DIY air cleaners: Tests, Part 2

(version of Feb 23, 2023)

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This work is being conducted in collaboration with an international team, within the @TheWHN Indoor Air Quality Group.

Links to related documents:

- Part 1 of this report
- CADR: Tests, Interpretation and Sizing
- Video on DIY construction and test (in Spanish)

Outline

This document contains the results obtained for different configurations of DIY air cleaners.

Parameters measured in the tests:

- **Flow rate** passing through the filter(s). This was measured with a bench designed according to ISO 5801 (with multi-nozzle plate).
- Electrical **power** consumed by the fan
- **Noise**, using a calibrated sound meter and expressed in dB(A). measured at 1 m from the fan, at three different locations: front, back and side of the fan.

CADR is estimated from measured flow rates by multiplying by the filter efficiency:

CADR=(Air flow rate)x(Filter efficiency)

The following filter efficiencies will be applied in this document:

- HEPA filters H12 and superior: 100%
- HEPA H11: 95%
- MERF13/ePM1 55%/F7 filters: 70%

Some uncertainty must be admitted in these values, due to variability among filters of the same class and also because it is not clear which range of aerosol sizes is more adequate to evaluate viral load. For filters with efficiencies <100%, both air flow rate and CADR are provided, so that the latter can be recalculated If better estimates are available.

The document is named '**Part 2**' because it can be considered as a second part of a previous report (Nov/2020). This one and the accompanying video can be found in the following links:

Ref. 1 - DIY Air Cleaners: Tests and Observations, 14/Nov/2020

Ref. 2 - Video with description of a single-panel version (+ gym fan) - In Spanish

The data for the different fan/filter combinations are presented in different sections. Further tests and calculations are in progress and new results will be included when available.

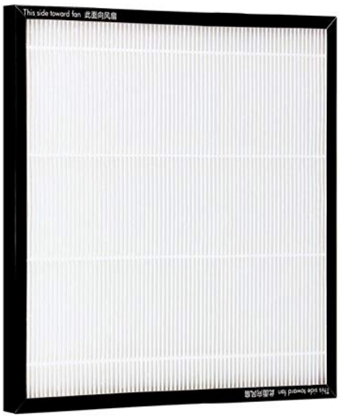
The configurations/sections included in this version of the document are:

1. Honeywell Turbo HT900 + SmartAir’s HEPA H12
2. Honeywell Turbo HT900 + Airbon’s Sqair HEPA H11
3. Honeywell Turbo HT900 + Cylindrical HEPA H13
4. Orbegozo BF0138 + SmartAir’s HEPA H12
5. Duronic Pedestal FN30 + MERV13/F7 panels
6. Honeywell Turbo HT900 + IKEA Starkvind
7. Cage fan (120 W) + IKEA Starkvind
8. Cage fan (120 W) + MERV13/F7 panels
9. Cage fan (120 W) + 4-filter boxes

1. Honeywell Turbo HT900 + HEPA H12

This section reports the results obtained for different configurations of a DIY air cleaner built with the following elements:

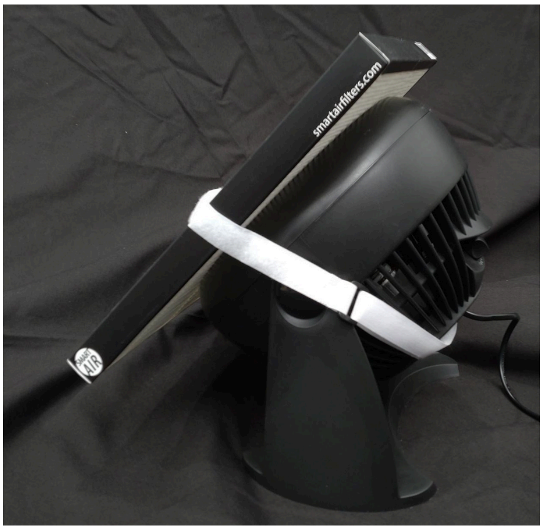
- Fan: Honeywell Turbo HT900 (30 W)
- Filter: SmartAir HEPA H12 filters, 12”x12” (supplied by Airbon.co.uk)



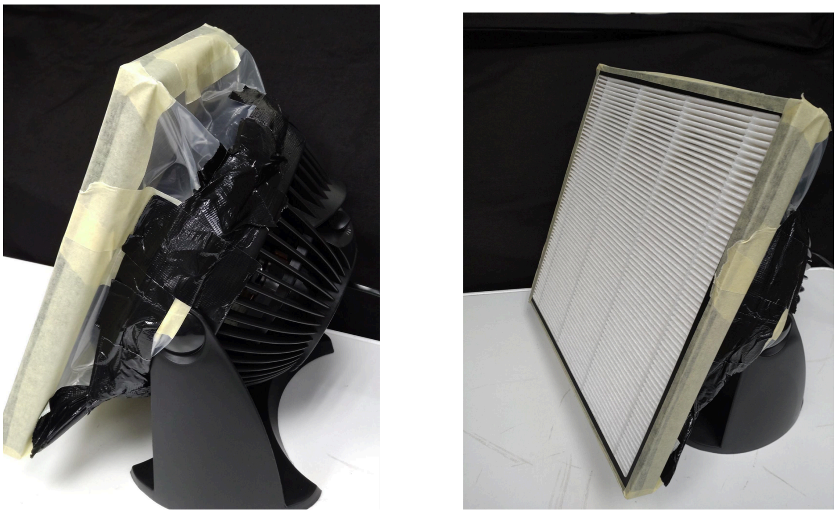
The configurations tested include:

- Single panel, filter strapped on fan.
- Single panel, sealed with a plastic film (*flow sheath*). Without and with a gap between fan and filter.
- CR box configuration with 4 filters

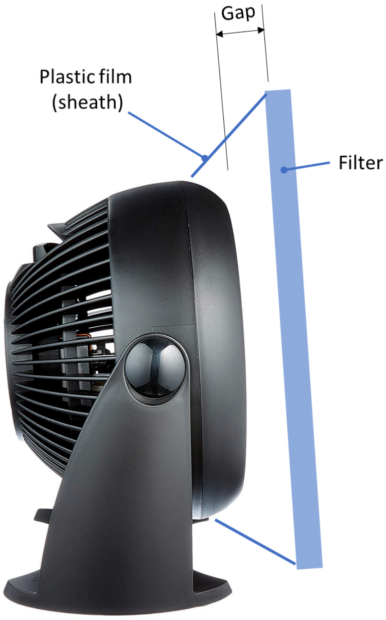
The gaps indicated correspond to the distance between the fan front and the filter face (see sketch). The 3 cm gap was fixed by using a few small spacers between fan and filter. The 10 cm gap is approximate, representative of a very wide gap.



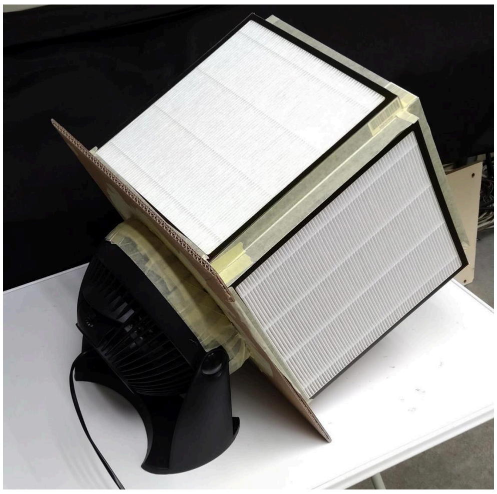
Single panel, filter strapped on fan



Single panel, with flow sheath


Gap
Plastic film (sheath)
Filter

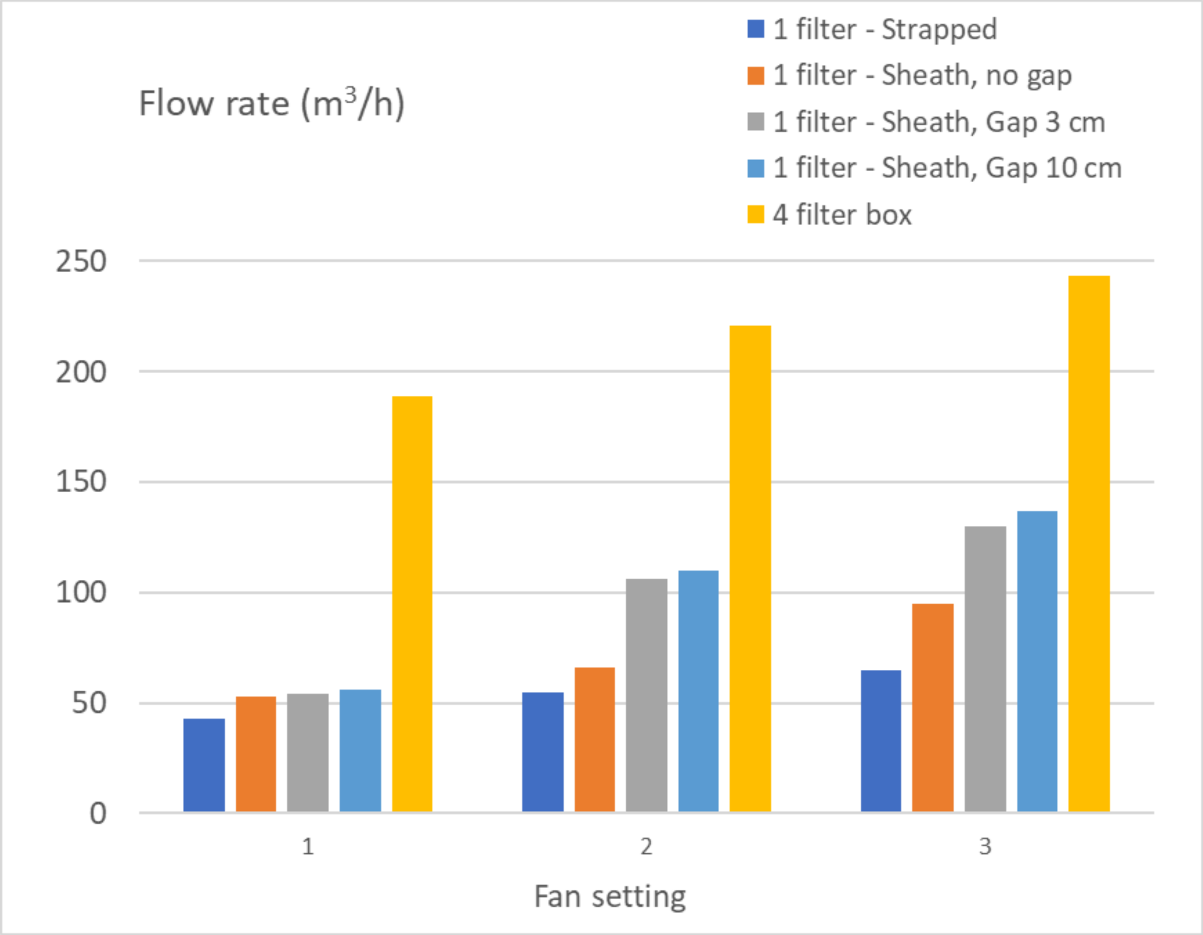
Sheath and gap

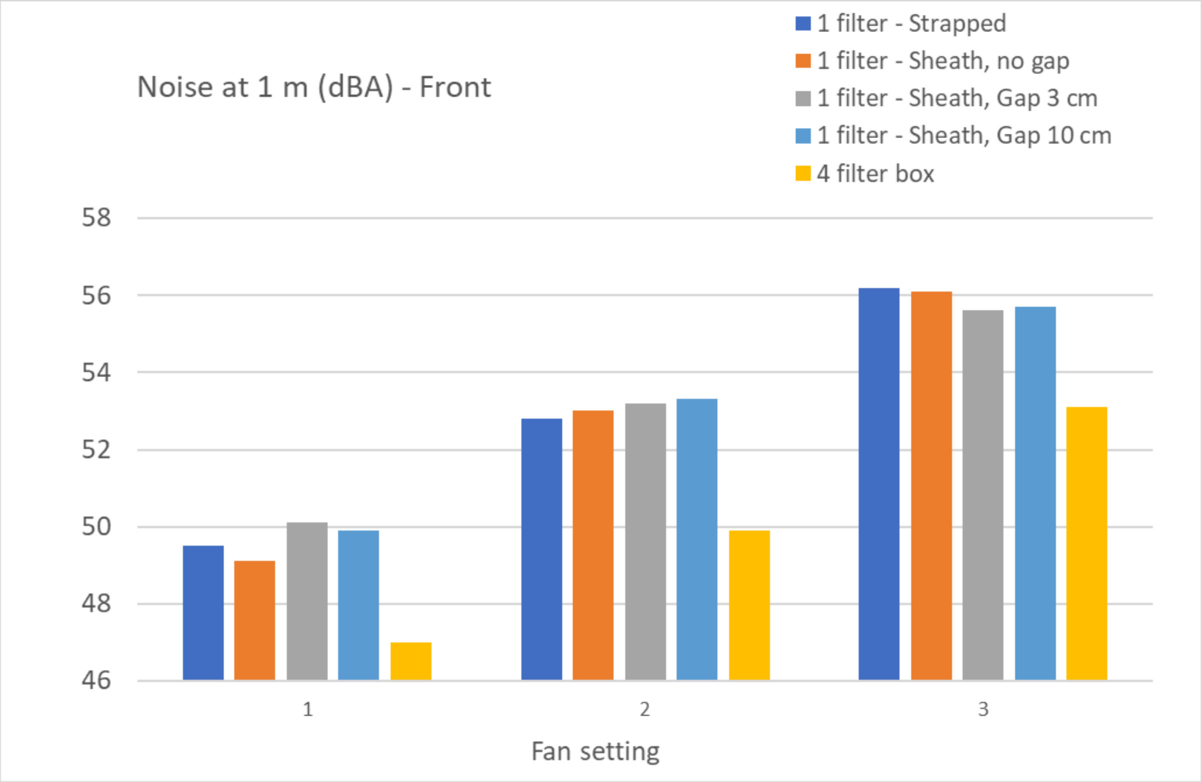


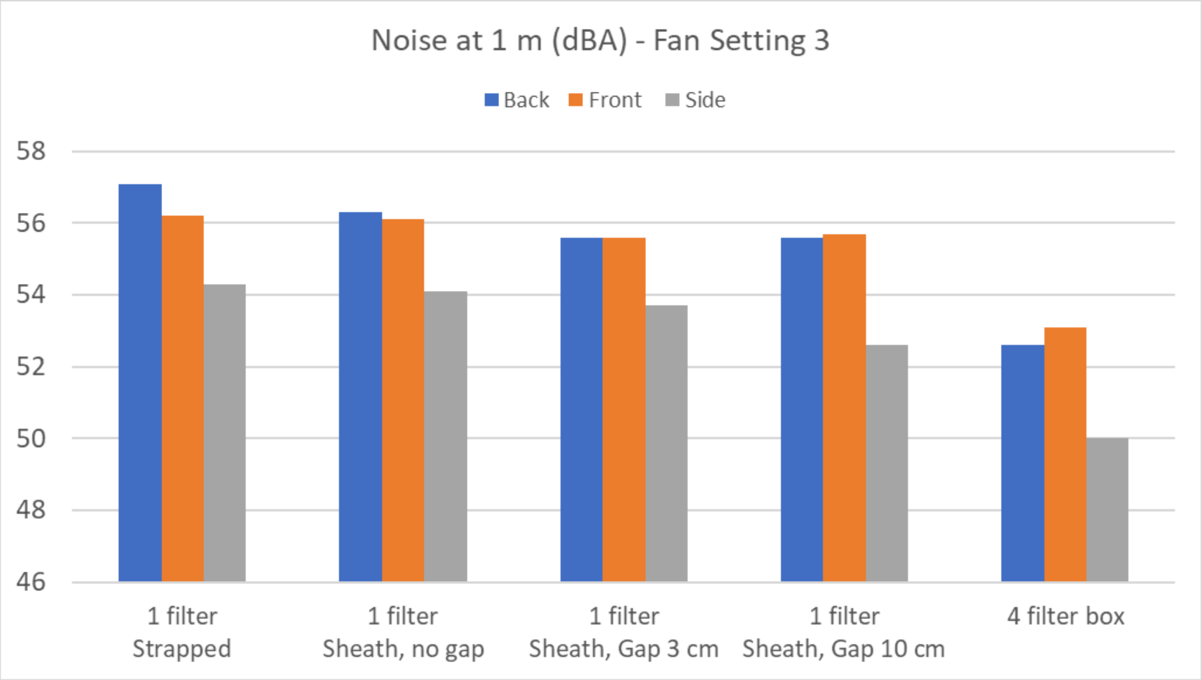
4-filter box

The following table and graphs display the results for different configurations and speed settings. CADR was calculated from measured air flow rates by applying a filtration efficiency of 99.5% for H12.

	Setting	CADR (m3/h)	Power (W)	Noise at 1 m (dBA)		
				Back	Front	Side
1 filter - Strapped	1	43	20.0	50.3	49.5	47.8
	2	55	23.9	53.2	52.8	52
	3	65	29.4	57.1	56.2	54.3
1 filter - Sheath, no gap	1	53	20.5	48.4	49.1	48.1
	2	66	24.5	52.3	53	51.2
	3	95	29.7	56.3	56.1	54.1
1 filter - Sheath, Gap 3 cm	1	54	21.0	49.2	50.1	48.1
	2	106	24.3	52.1	53.2	50.9
	3	130	29.9	55.6	55.6	53.7
1 filter - Sheath, Gap 10 cm	1	56	20.5	50	49.9	47.2
	2	110	24.0	52.6	53.3	50
	3	137	29.4	55.6	55.7	52.6
4 filter box	1	189	20	47.1	47	45.7
	2	221	23.7	49.9	49.9	47.5
	3	243	29.8	52.6	53.1	50




Noise at 1 m (dBA) - Front
1 filter - Strapped
1 filter - Sheath, no gap
1 filter - Sheath, Gap 3 cm
1 filter - Sheath, Gap 10 cm
4 filter box
58
56
54
52
50
48
46
1
2
3
Fan setting


Noise at 1 m (dBA) - Fan Setting 3
Back
Front
Side
58
56
54
52
50
48
46
1 filter Strapped
1 filter Sheath, no gap
1 filter Sheath, Gap 3 cm
1 filter Sheath, Gap 10 cm
4 filter box

For the single-panel configuration, widely different flow rates were measured depending on the configuration. In particular, the flow sheath significantly increases the flow rate. For setting 3, it rises from 65 m^3/h w/o sheath to 95 m^3/h when the sheath is added (but filter leans on fan) and reaches 137 m^3/h with sheath plus a large gap of approx 10 cm between fan and filter. A narrower gap of 3 cm yields a marginally lower flow rate (130 m^3/h) and results in a more compact design.

The reason for the improvements achieved with the flow sheath and the gap is thought to be a better use of the filter surface area. Without the plastic film, the air only passes through the central circular area in front of the fan blades, the rest of the filter surface (about one half of the total surface area) not being used. When the sheath is added, with no gap, some air leaks between fan and filter and pressurizes the space enclosed by the plastic film, yielding some additional flow through the filter corners that stick out of the fan circle. If the filter is mounted with some gap, the air can freely flow through the whole filter area. As a result, mounting with flow sheath + gap more than doubles the flow rate.

(Further data and discussion on the effect of the flow sheath can be found in tinyurl.com/FanFilter. Video on single-panel DIY in this link -in Spanish-).

The flow rate can still be increased (at max speed, by 77%, from 137 to 243 m^3/h) with four filters assembled as a Corsi-Rosenthal box.

As for noise, both the sheath and the gap yield some reductions for the highest fan speed; however, the effect is different for other fan settings. The box further reduces noise by 2-3 dB(A).

2. Honeywell Turbo HT900 + HEPA H11

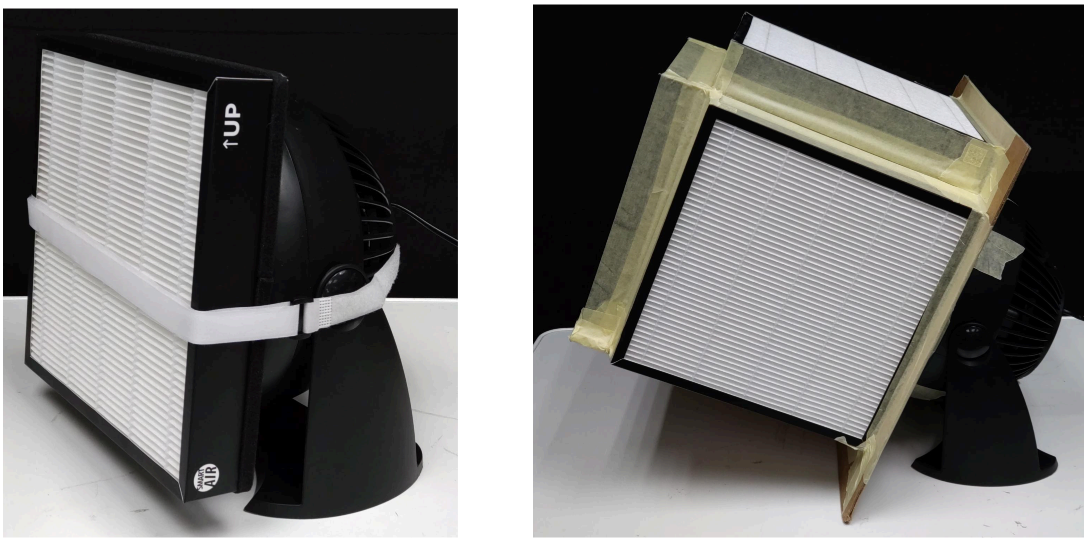
The fan Honeywell HT900 was also tested with filters Sqair HEPA H11 supplied by Airbon.co.uk. The differences with respect ot the H12 reported above are:

- According to the standards, filtration efficiency for H11 is 95% (instead of 99.5% for H12)
- Size: 10,5x10,5x2 (compared to 12x12x1 for H12)

As for H12, the configurations tested include:

- Single panel, filter strapped on fan.
- Single panel, sealed with a plastic film (*flow sheath*). Without and with a gap between fan and filter (gaps of 1 and 3 cm were tested in this case).
- CR box configuration with 4 filters

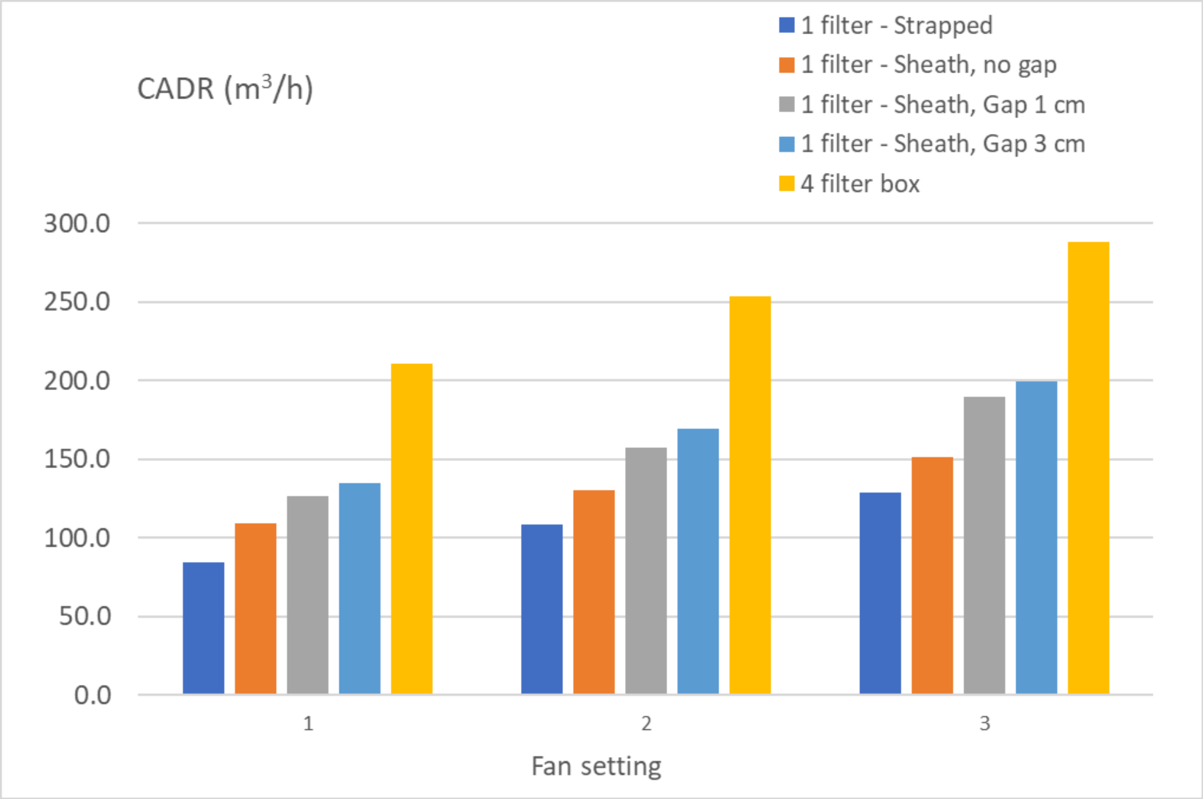
The following pictures show the versions with a strapped panel and CR box.

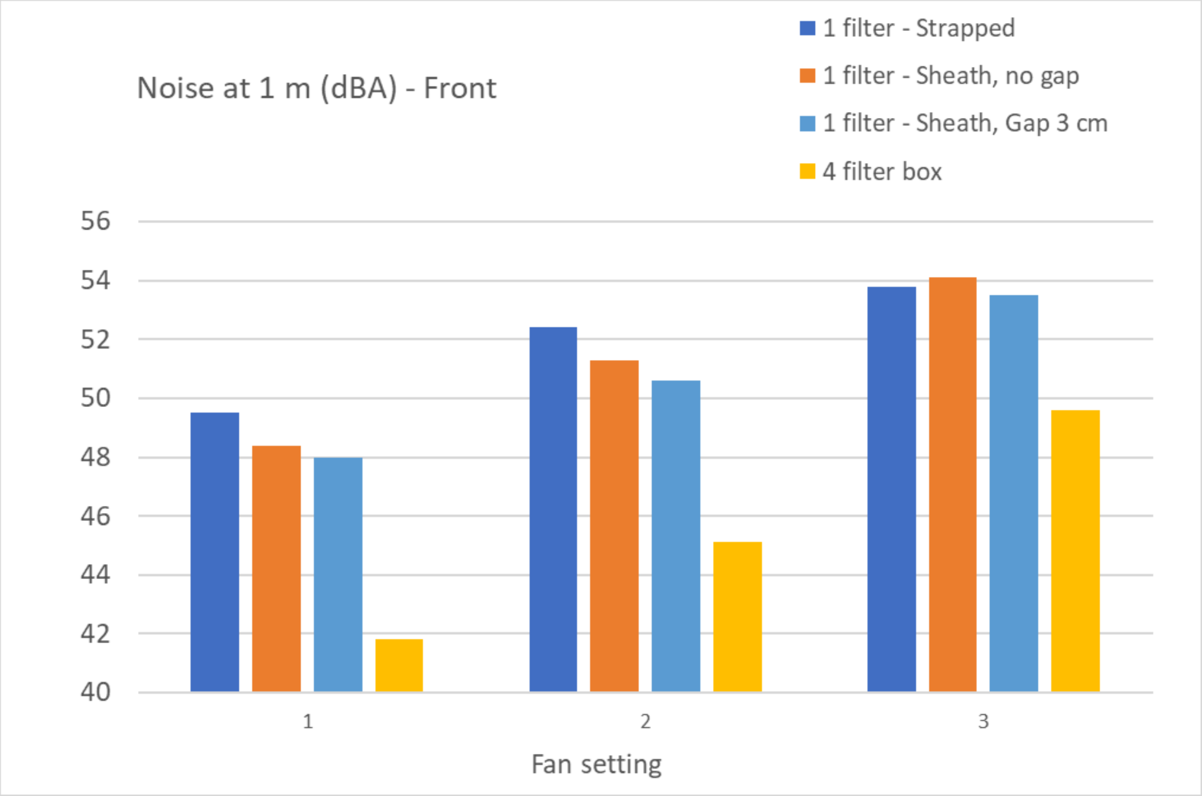


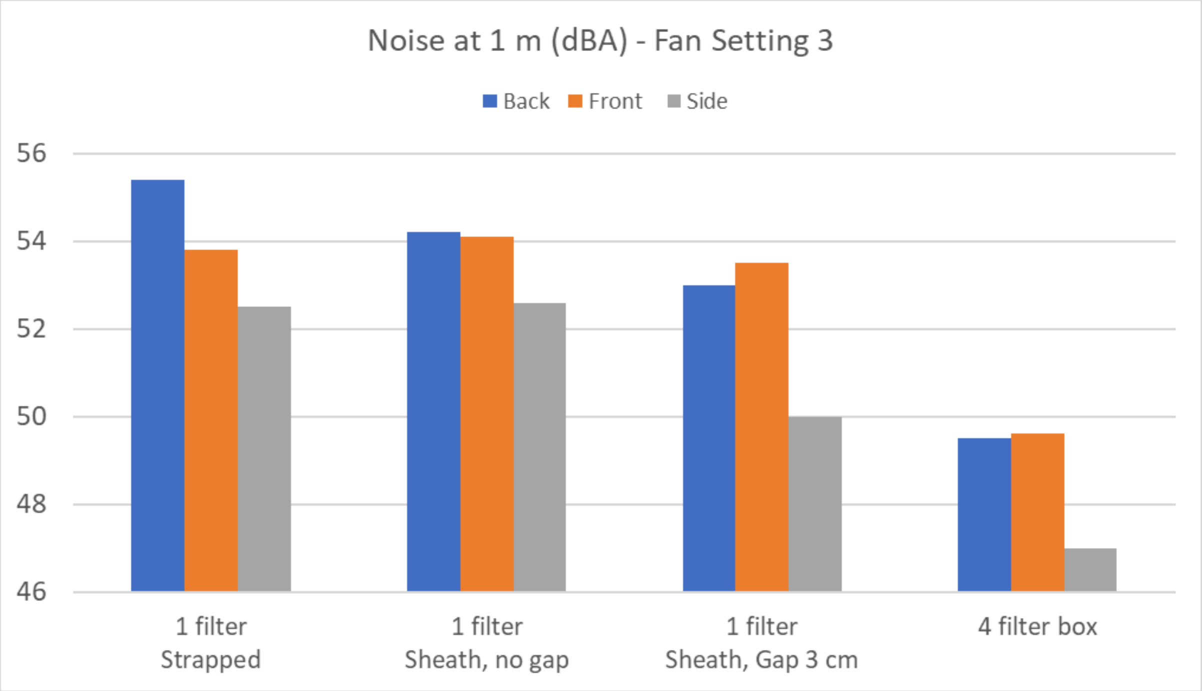
Single panel, strapped and CR box versions

The results of the tests are shown in the following table and figures. A filtration efficiency of 95% was applied to convert flow rate into CADR. The widest gap tested in this case was 3 cm. In view of the results obtained for H12, a small increment could be achieved with much wider gaps. This could be estimated from the relative differences reported in the previous section between 3 and 10 cm.

	Setting	Flow rate (m3/h)	CADR (m3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
1 filter - Strapped	1	89.3	84.8	20.2	50.1	49.5	47.5
	2	114	108.3	24.2	53.8	52.4	50
	3	136	129.2	30.1	55.4	53.8	52.5
1 filter - Sheath, no gap	1	115	109.3	19.6	48.6	48.4	47.2
	2	137	130.2	23.4	51.6	51.3	49.5
	3	159	151.1	29.1	54.2	54.1	52.6
1 filter - Sheath, Gap 1 cm	1	133	126.4	20.3			
	2	166	157.7	24.6			
	3	200	190.0	29.9			
1 filter - Sheath, Gap 3 cm	1	142	134.9	20.3	48.3	48	45.3
	2	178	169.1	24.4	50.5	50.6	47.9
	3	210	199.5	30.0	53	53.5	50
4 filter box	1	222	210.9	20.3	42.1	41.8	40.7
	2	267	253.7	24.4	45.7	45.1	43.9
	3	303	287.9	29.8	49.5	49.6	47




Noise at 1 m (dBA) - Front
1 filter - Strapped
1 filter - Sheath, no gap
1 filter - Sheath, Gap 3 cm
4 filter box
56
54
52
50
48
46
44
42
40
1
2
3
Fan setting


Noise at 1 m (dBA) - Fan Setting 3
Back
Front
Side
56
54
52
50
48
46
1 filter
Strapped
1 filter
Sheath, no gap
1 filter
Sheath, Gap 3 cm
4 filter box

3. Honeywell Turbo HT900 + Cylindrical HEPA H13

The same fan Honeywell HT900 was also tested with a cylindrical Dyson filter. The technical information found does not specify the filter grade but indicates a filtration efficiency of 99.97%, suggesting it is a H13. The dimensions are: diameter 7”, length 6”, thickness 0,5”.

The picture shows the filters and how it is mounted on the Honeywell fan (the upper side is closed with a lid). This appears as a very compact configuration, allowing simpler construction than with panel filters.

The flow rates measured at the test bench are listed in the table. This combination resulted in a very low flow rate and CADR (both are equivalent in this case, given the very high filtration efficiency). ACH 6 is a common recommendation for sizing of portable filters, so that the use of this device would be limited to a room of 2,2 m^3 (less than 1 m^2). It is clear that this combination is practically useless as a protection against COVID (or, in general, for removing aerosols).

These results can be compared to those reported in previous paragraphs for H12 or H11, yielding more than 10 times higher CADR. Even though their filtration efficiency is slightly lower (99.5 and 95%, respectively), for the same fan, they cause much less flow resistance, resulting in a much higher flow rate and, as its CADR indicates, can remove >10 times more aerosols from the ambient.

	Setting	Flow rate (m3/h)	CADR (m3/h)	Power (W)
Honeywell Turbo HT900 + Cylindrical H13 (Dyson)	1	5.8	5.8	20.7
	2	9.7	9.7	25.4
	3	13.2	13.2	31.5

4. Orbegozo BF0138 + HEPA H12

SmartAir's HEPA H12 filters (size 12x12x1) were also tested with the fan Orbegozo BF0138 (40 W, 30 cm). This is the fan identified as BF1 in Part 1 (tinyurl.com/FannFilter).

Orbegozo
Confort Plus

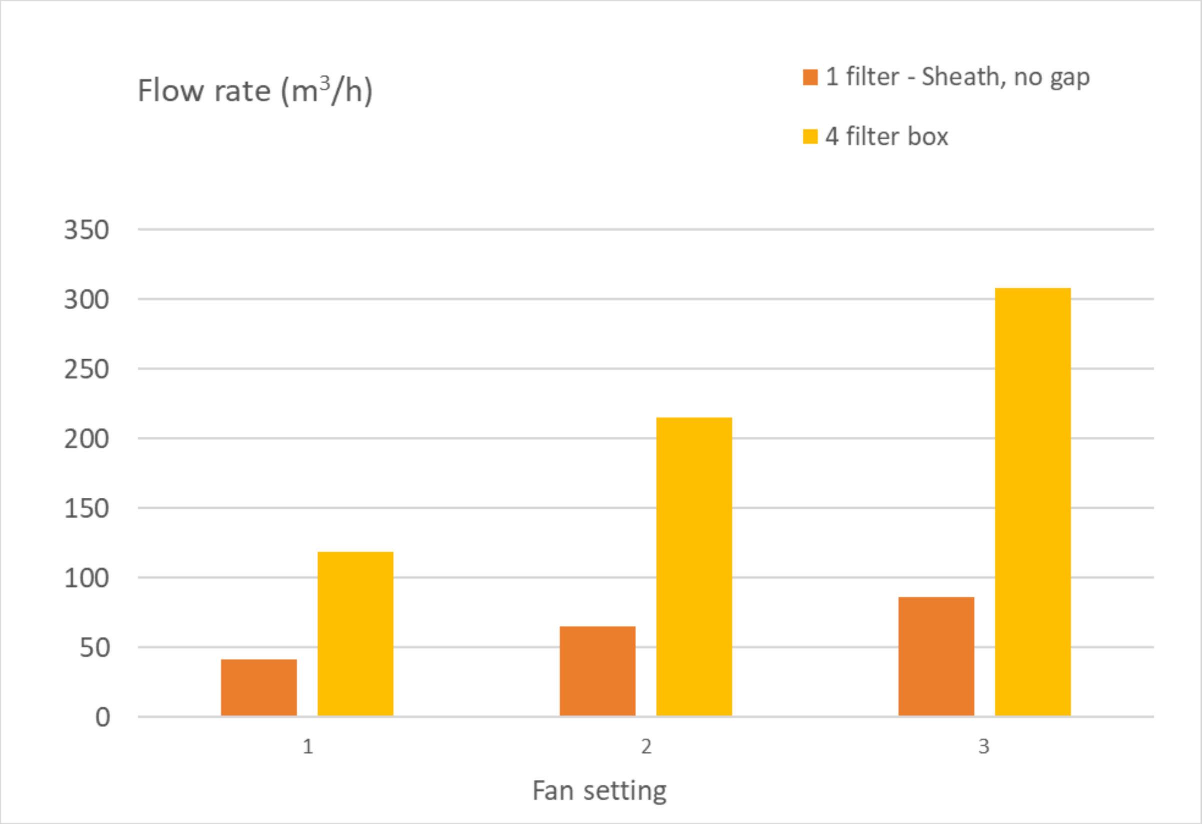
Orbegozo BF 0138

The air flow rate was measured for two configurations:

- Single panel, sealed with a plastic film (*flow sheath*). No gap was left between filter and fan in this case; however, the increase in flow rate due to the gap is expected to be smaller than for the Honeywell Turbo due to the larger diameter of the grill (same as the side of the filters).
- CR box configuration with 4 filters

Noise tests were not carried out in this case.

	Setting	Flow rate (m3/h)	Power (W)	Noise at 1 m (dBA)		
				Back	Front	Side
1 filter - Sheath, no gap	1	42	38.0			
	2	65	44.0			
	3	86	53.0			
4 filter box	1	119	44			
	2	215	46			
	3	308	49			

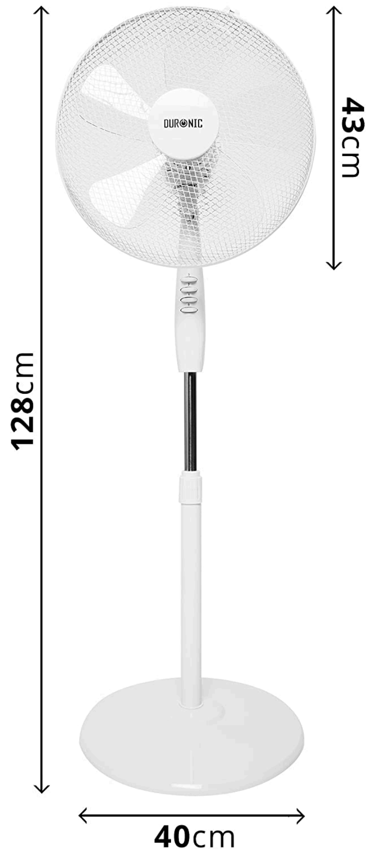


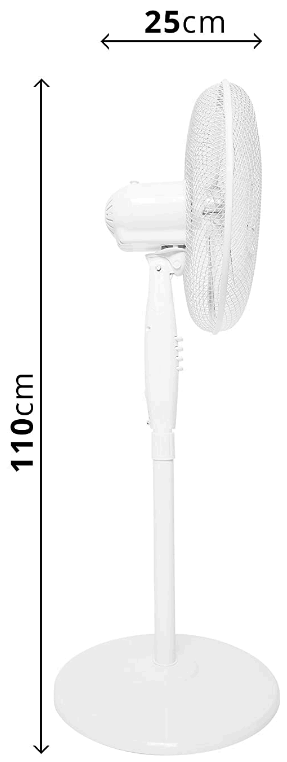
5. Duronic FN30 + MERV13/F7 panels

This section reports the results obtained for different configurations of a DIY air cleaner built with the following elements:

- Fan: Duronic Pedestal Fan FN30, 60W, 16” (40 cm blades).
- Filters:
    - Camfil Ecopleat F7 (ePM1 55%), Size 24x24x2.
    - 3M Filtrete 1900, MERV13, Size 20x20x1.
    - Aerostar MERV13, Size 20x22x1.

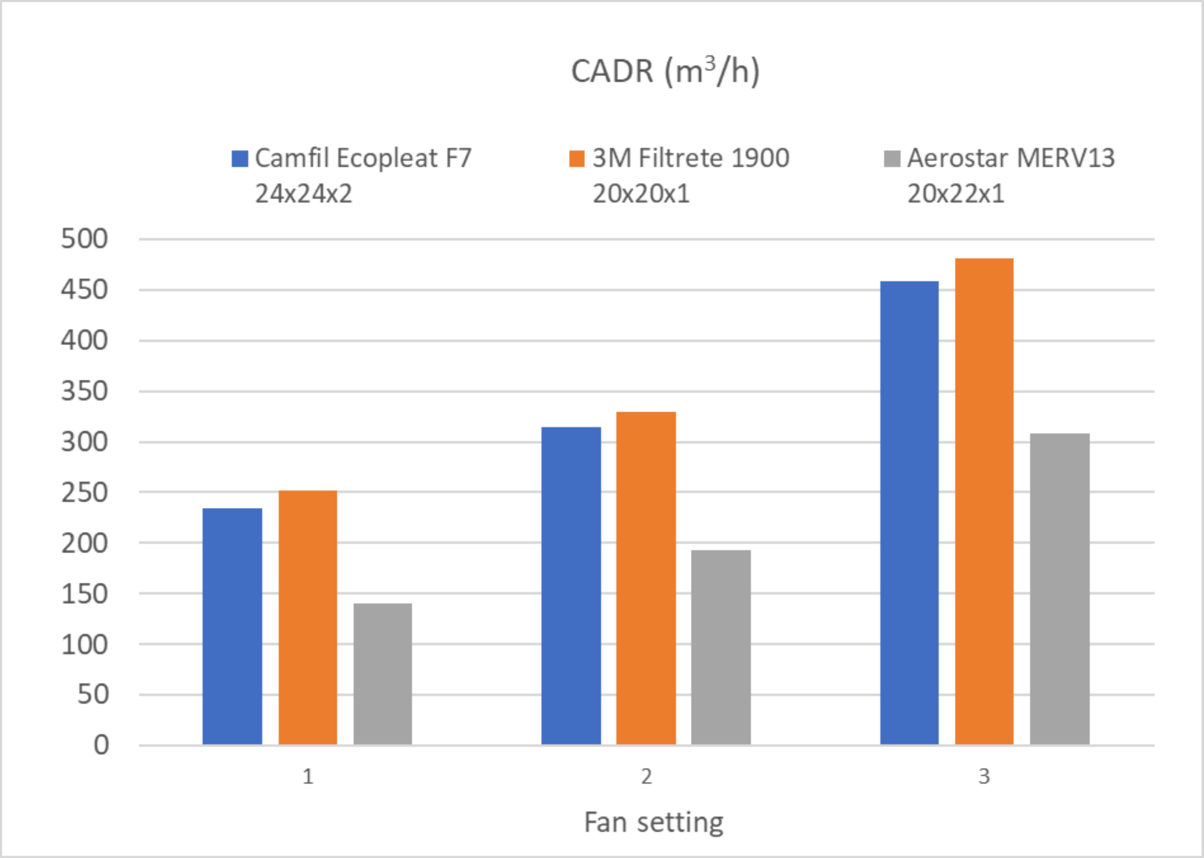
The following images show the fan with dimensions and with a filter mounted on it. Fan and filter are assembled using a plastic film, which acts as a flow sheath and allows using the full filter area (if mounted without this plastic envelope, flow rate would be significantly lower).

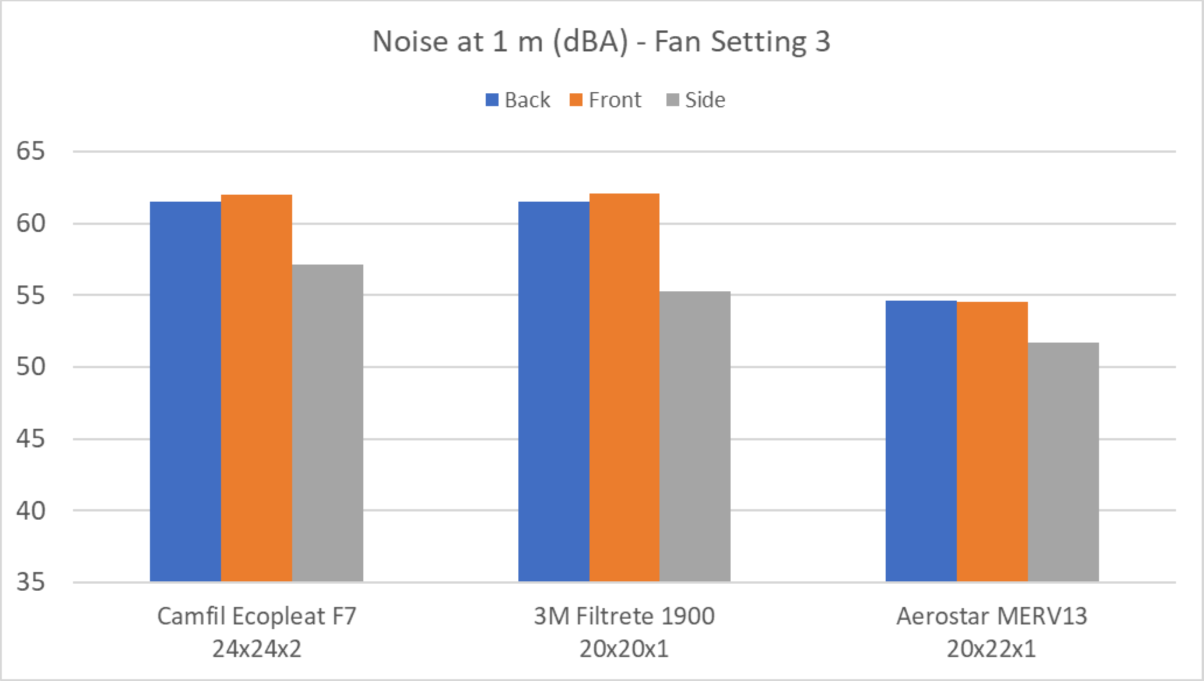


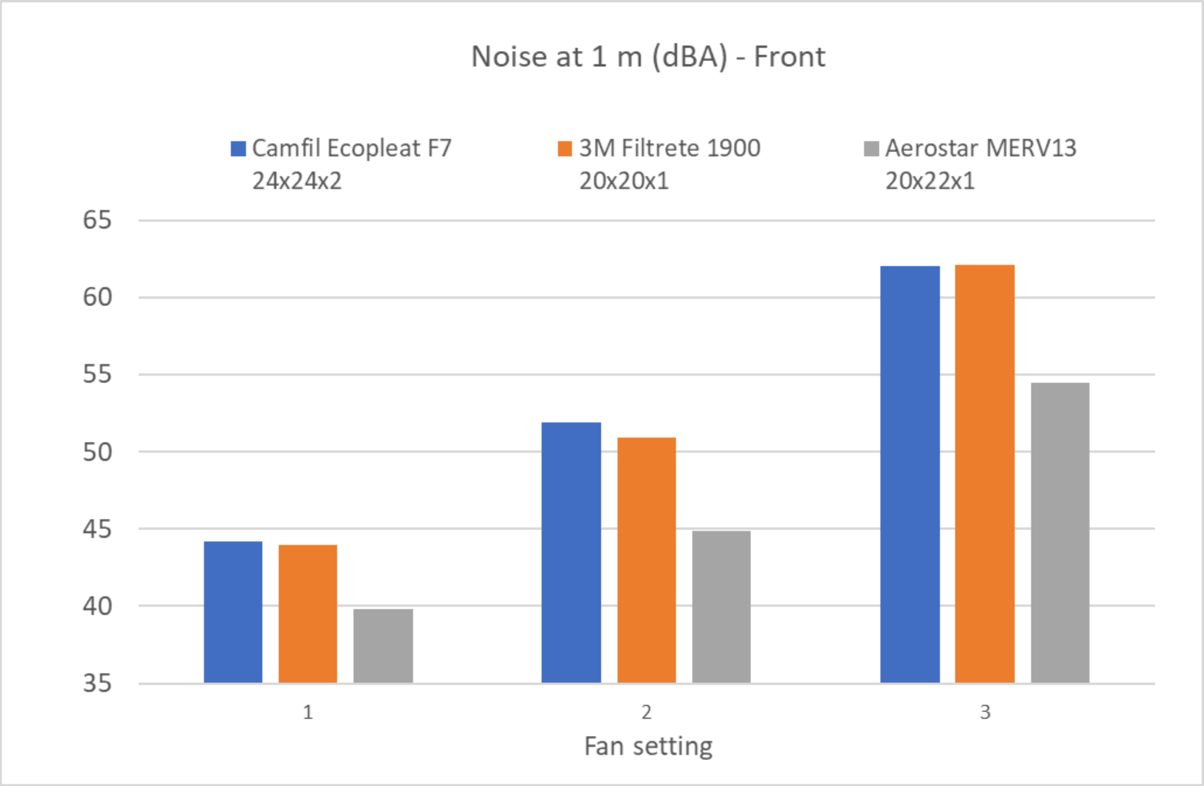


The following table and graphs display the results of the tests.

	Setting	Flow rate (m3/h)	CADR (m3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
Camfil Ecopleat F7 24x24x2	1	335	235	45.8	44.9	44.2	41.2
	2	450	315	48.8	51.4	51.9	47.1
	3	655	459	56.9	61.5	62	57.1
3M Filtrete 1900 20x20x1	1	359	251	42.2	44.1	44	40.2
	2	470	329	50.0	51	50.9	46.1
	3	688	482	56.2	61.5	62.1	55.3
Aerostar MERV13 20x22x1	1	201	141	44.6	40.1	39.8	38.4
	2	276	193	50.9	44.2	44.9	42.8
	3	440	308	59.4	54.6	54.5	51.7




Noise at 1 m (dBA) - Fan Setting 3
Back
Front
Side
65
60
55
50
45
40
35
Camfil Ecopleat F7 24x24x2
3M Filtrete 1900 20x20x1
Aerostar MERV13 20x22x1


Noise at 1 m (dBA) - Front
Camfil Ecopleat F7 24x24x2
3M Filtrete 1900 20x20x1
Aerostar MERV13 20x22x1
65
60
55
50
45
40
35
1
2
3
Fan setting

6. Honeywell Turbo HT900 + Filter IKEA Starkvind

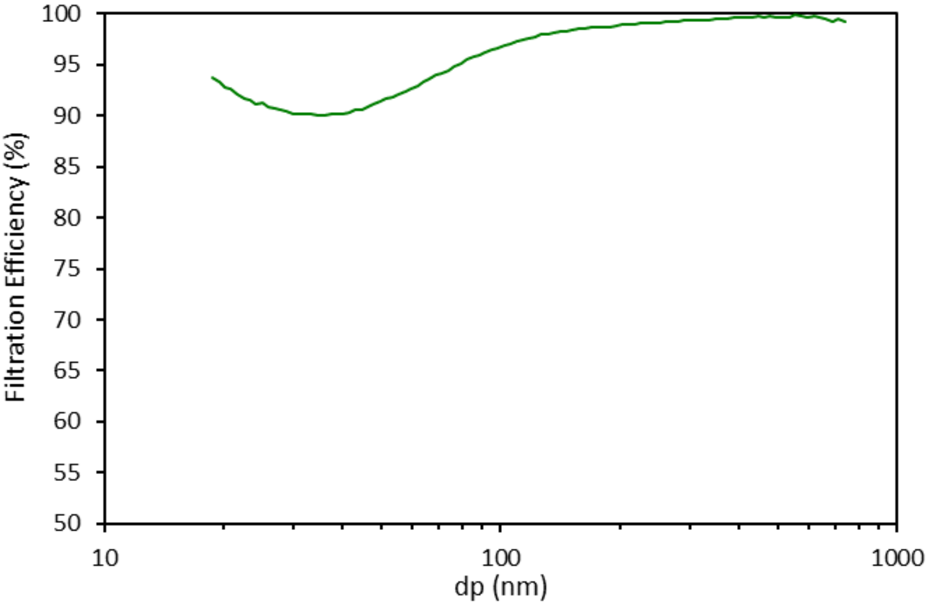
The fan Honeywell Turbo HT900 was also tested in combination with the filter Starkvind (IKEA).

In Spain: https://www.ikea.com/es/es/p/starkvind-filtro-extraccion-particulas-30461943/

In US: https://www.ikea.com/us/en/p/starkvind-filter-for-particle-removal-30461943/

The information provided varies with the country. For example, the US website specifies that it is tested according to EN 1822-1 and corresponds to EPA12.

A sample of the filter material was tested at our laboratory, using the instruments and method described in tinyurl.com/CADRtests. This graph shows the efficiency curve obtained for particles under 1 micron. Although some decay was detected below 100 nm, the efficiency is close to 100% above 200 nm. Considering what is known about the size distribution of respiratory aerosols[1], a FERA (filtration efficiency of respiratory aerosols) of 95% is considered a conservative lower limit for the actual efficacy of this filter to remove potentially pathogen-containing aerosols. So, CADR will be estimated by multiplying measured flow rate by FERA=95%.



Filtration curve measured for a sample of filter IKEA STARKVIND.
Measured with SMPS TSI 3936, for an air velocity of 7.5 cm/s.

The dimensions of the filter are 37x29 cm and 4 cm thick.

Two configurations have been tested:

- Single panel, with flow sheath and a gap of 1 cm between filter and fan.
- 4-filter, CR-type box

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[1] Further details in Section 5 of tinyurl.com/CADRtests

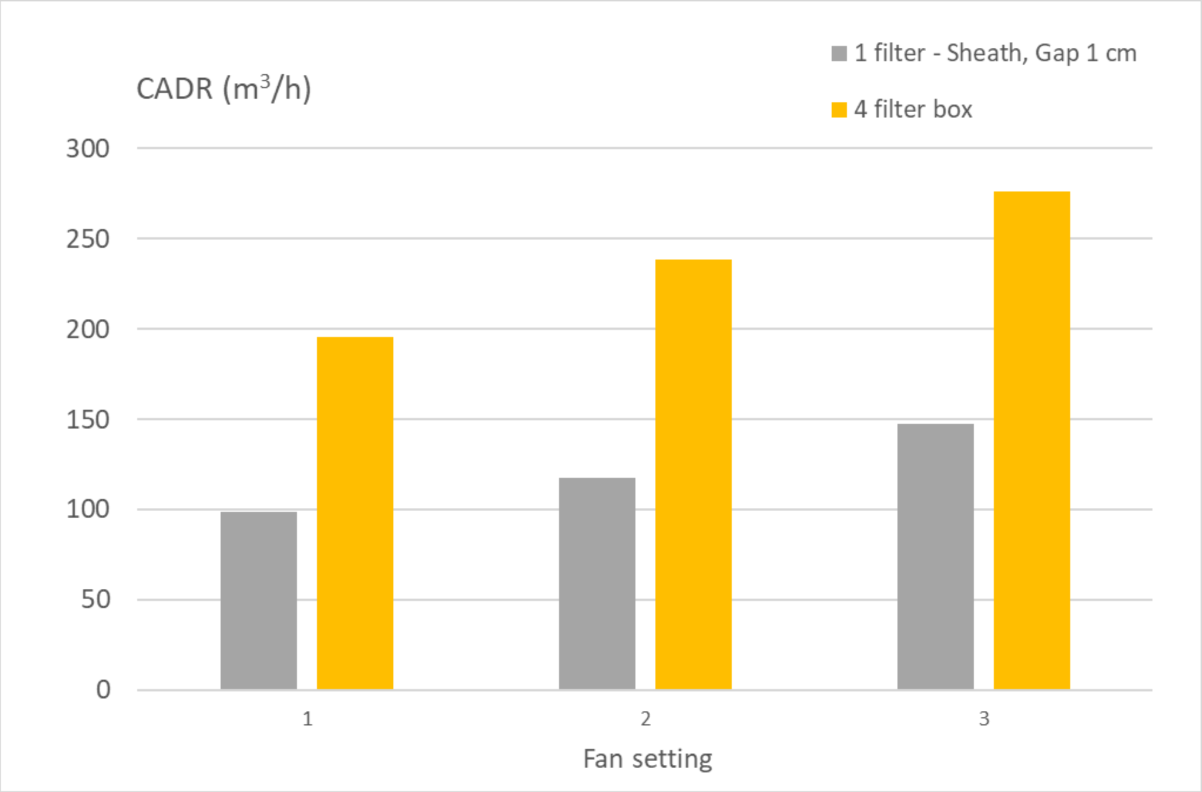
The following table and figures display the measurements of flow rate, power consumed and noise performed at the three speed settings for both configurations. CADR is calculated by applying a filtration efficiency of 95%.

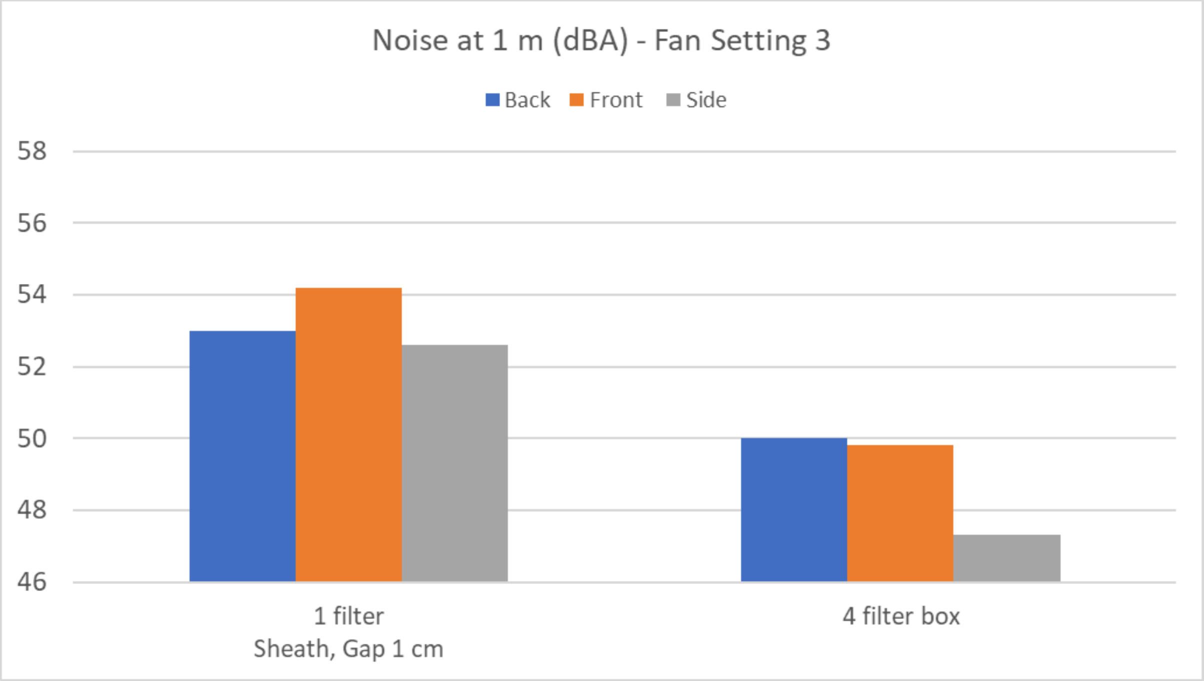
Flow rates and CADR are similar to those measured for Sqair H11 (see above) for the 4-filter box, and somewhat lower for the single panel. It should be noted that the measurements with one panel were performed with 1 cm gap; results with other configurations suggest that the CADR could increase by about 10% for larger gaps.

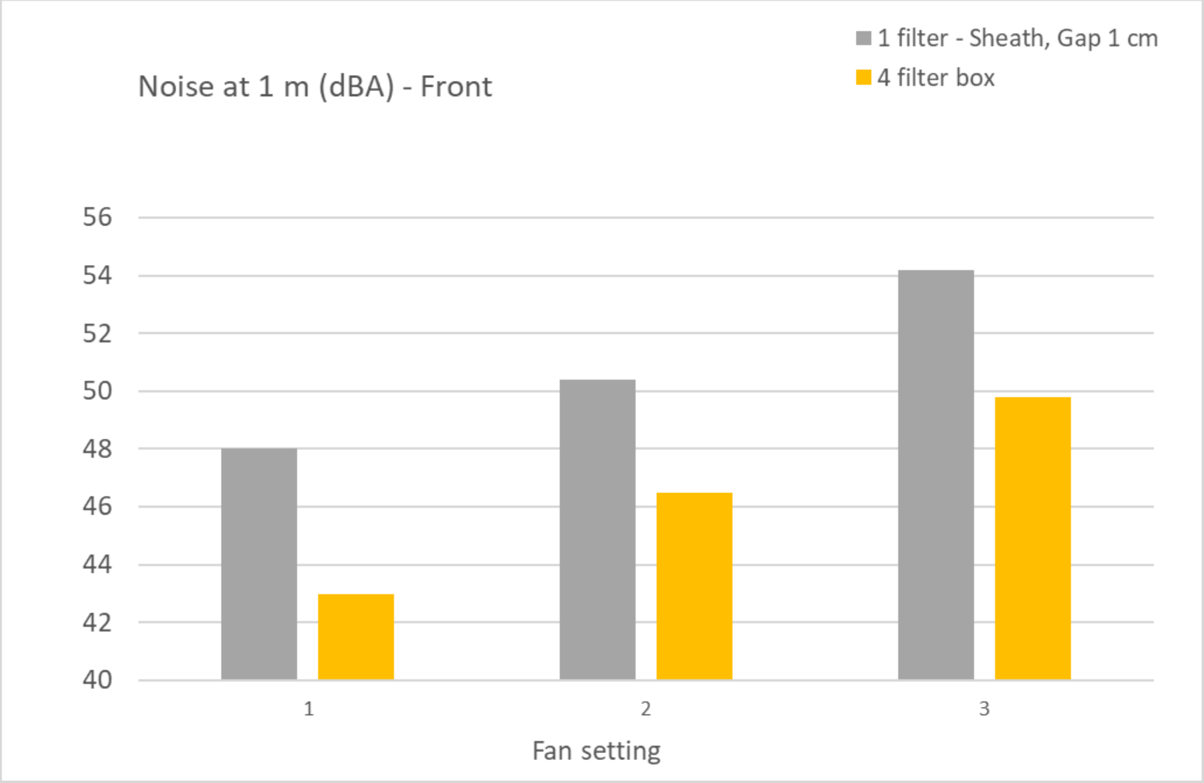
In general, CADR values are quite high given the relatively low power (and cost) of this fan. Also, noise is notably low, especially for the box: about 50 dBA at max (276 m^3/h), and below 47 dBA at mid speed, still with a quite decent flow rate of 238 m^3/h.

The cost of these filters is 12€ (Ikea Spain, online). If filtration efficiency is reasonable (let's say, ePM1 >50%), they seem a good candidate for DIY air cleaners.

	Setting	Flow rate (m^3/h)	CADR (m^3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
1 filter - Sheath, Gap 1 cm	1	104	98.8	20.5	42.1	48	44.9
	2	123.7	117.5	24.2	48.2	50.4	49
	3	155	147.3	29.5	53	54.2	52.6
4 filter box	1	206	195.7	20.4	43.1	43	41.7
	2	251	238.5	24.7	46.8	46.5	44.2
	3	291	276.5	30.2	50	49.8	47.3




Noise at 1 m (dBA) - Fan Setting 3
Back
Front
Side
58
56
54
52
50
48
46
1 filter
Sheath, Gap 1 cm
4 filter box


Noise at 1 m (dBA) - Front
1 filter - Sheath, Gap 1 cm
4 filter box
56
54
52
50
48
46
44
42
40
1
2
3
Fan setting

7. Cage fan (120 W) + Filter IKEA Starkvind

IKEA Starkvind filters were also tested with a 120 W cage (or gym) fan (45 cm). Same fan as OF1 in Part 1:

OF1

The same or very similar fans can be found in many other countries under different brands. For example, it can be purchased for 40€ in:

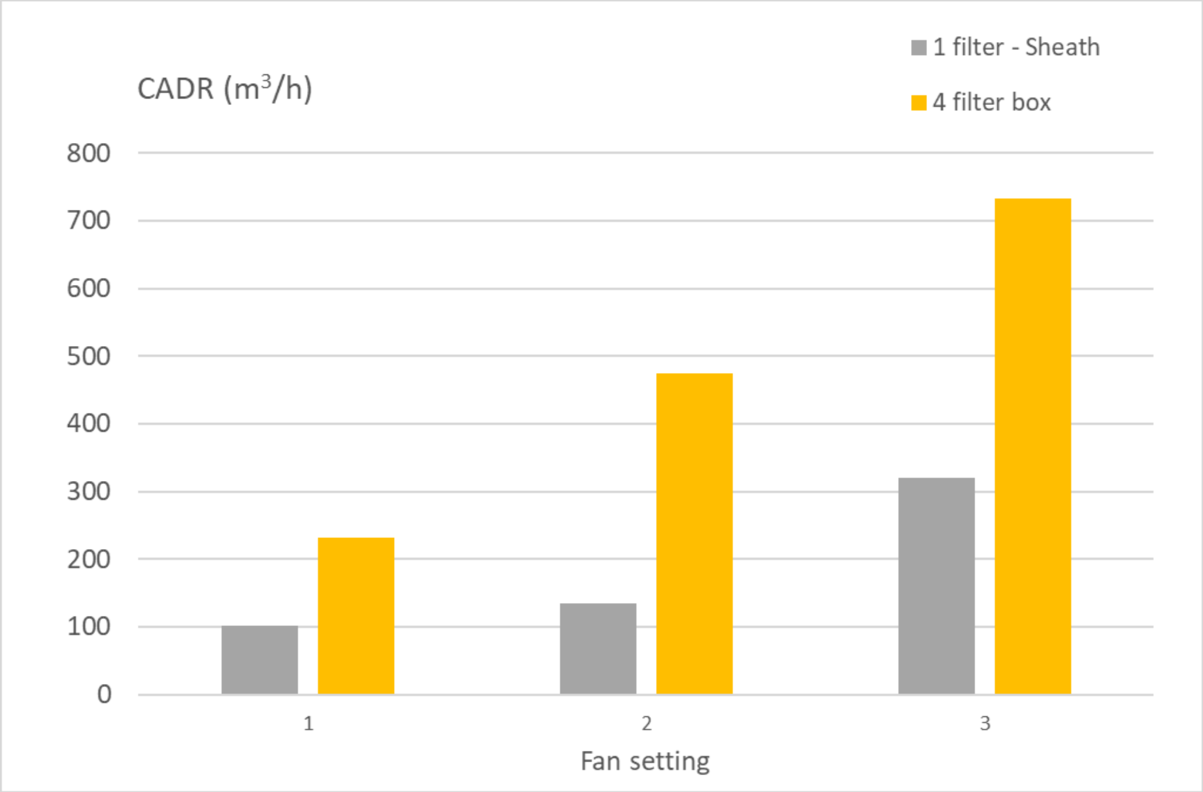
https://www.bricomart.es/ventilador-industrial-45cm-120w-cromo-10760981.html

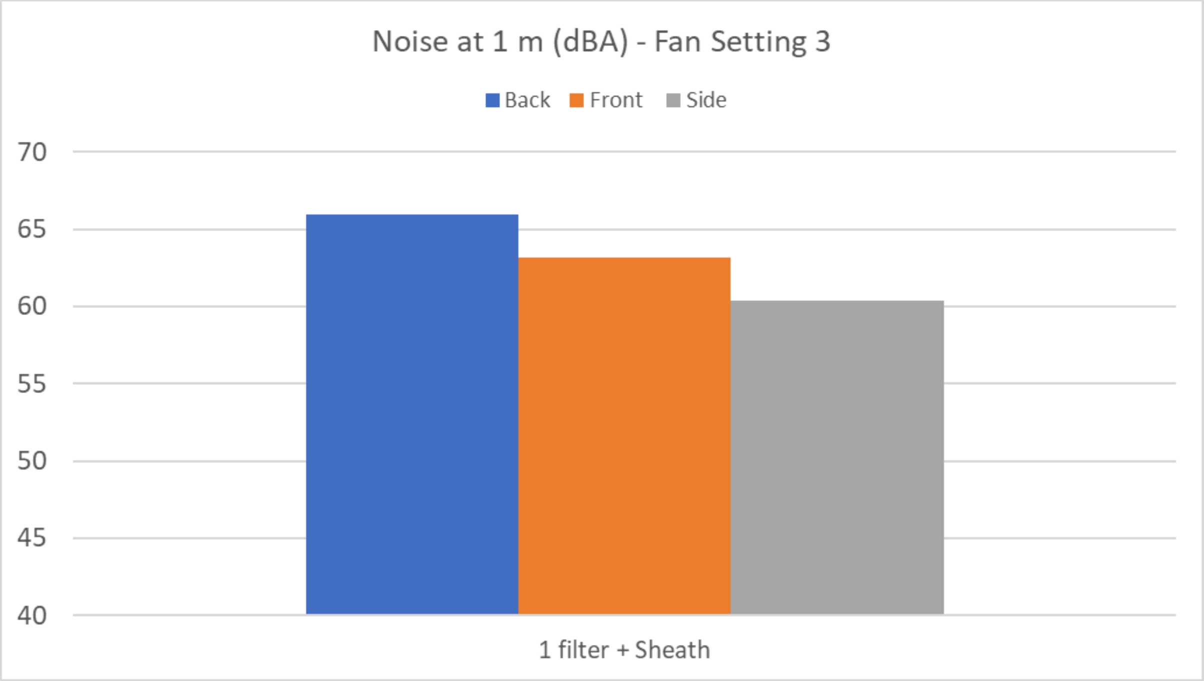
As with the Honeywell Turbo (see previous section), the tests include the two configurations: single panel and 4-filter box. A flow sheath (plastic film) was added in the single panel to include the whole filter area. No gap was needed in this case, the fan does not have an outer shroud that could close the flow path to the filter corners.

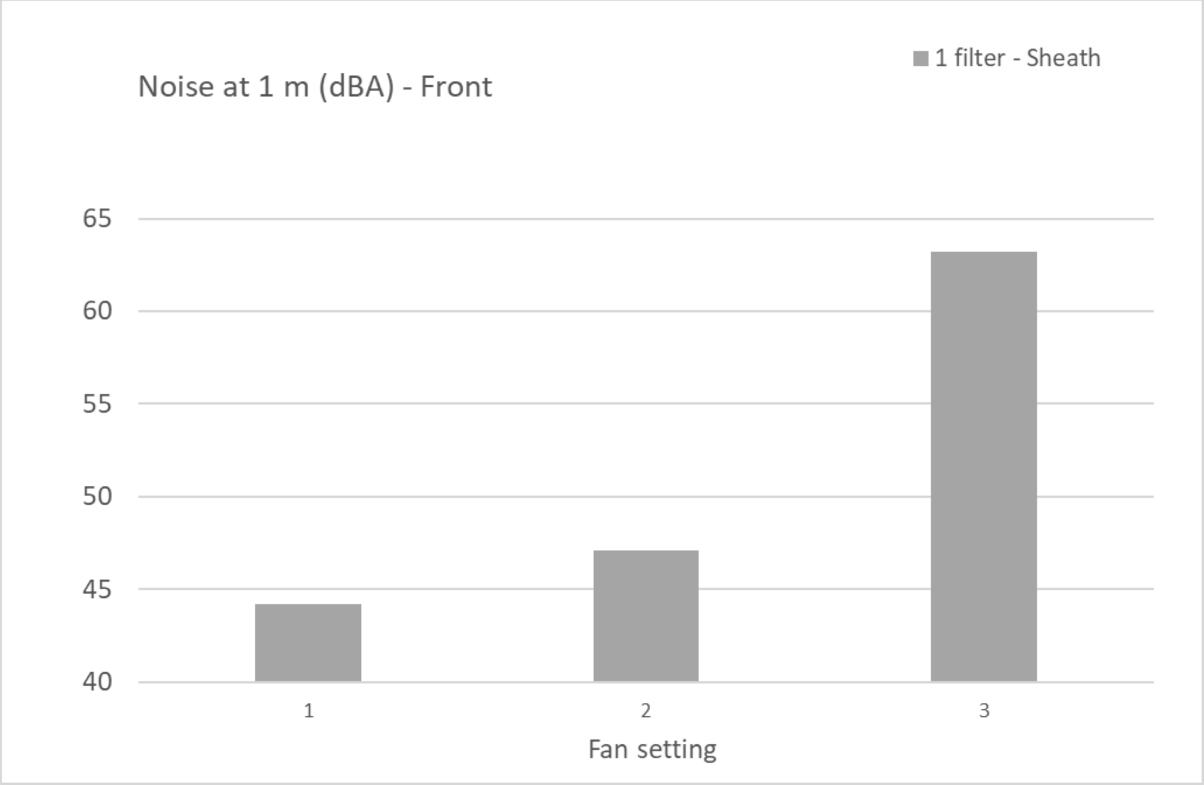
The following table and graphs display the results in the usual format. This combination yields quite high CADR: up to 733 and 475 m^3/h at max and mid speeds, respectively.

Noise was only measured for the single panel. From previous experience, the 4-filter box is expected to be somewhat quieter. The fan is quite loud at max speed, but could be useful in situations where noise is not a problem or for specific periods when some filtration boost is required. On the contrary, noise is significantly lower at mid and low speeds, still providing quite a good CADR (475 m^3/h at setting 2).

	Setting	Flow rate (m^3/h)	CADR (m^3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
1 filter - Sheath	1	108	102.6	102	45	44.2	43.7
	2	141	134.0	107	49.9	47.1	47.1
	3	337	320.2	128	66	63.2	60.4
4 filter box	1	244	231.8	101			
	2	500	475.0	105			
	3	772	733.4	116			




Noise at 1 m (dBA) - Fan Setting 3
Back
Front
Side
70
65
60
55
50
45
40
1 filter + Sheath

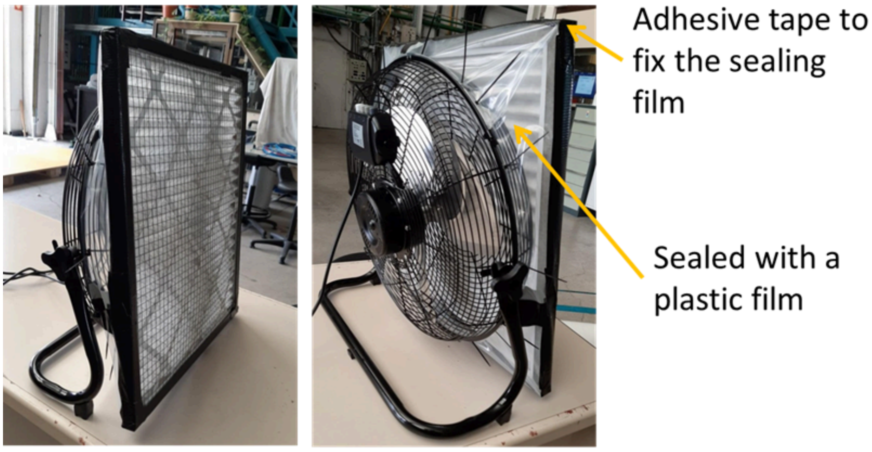

Noise at 1 m (dBA) - Front
1 filter - Sheath
65
60
55
50
45
40
1
2
3
Fan setting

8. Cage fan (120 W) + MERV13/F7 panels

This section reports the results for single panel configurations, with the cage fan (120 W, 45 cm) combined with several MERV13 / F7 panels:

- Camfil Ecopleat F7 (ePM1 55%), Size 24x24x2.
- Aerostar MERV13, Size 20x22x1.
- 3M Filtrete 1900, MERV13, Size 20x20x1.
- 3M Filtrete 2200, MERV13, Size 20x20x1.

The results correspond to a single panel configuration, as shown in the picture (in this case, with Aerostar) or in this video. The plastic film (flow sheath) is effective to significantly increase the flow rate and CADR, with respect to the version with the filter just strapped on the fan (data and discussion in Part 1).


Adhesive tape to fix the sealing film
Sealed with a plastic film

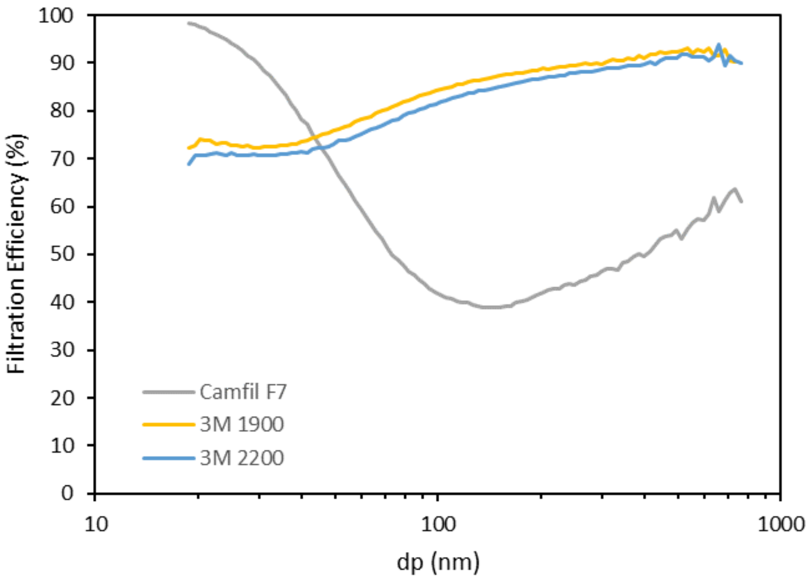
Sealed assembly OF1+F1”

Some of the filters were tested for filtration efficiency, following the method described in Section 4 of the report on CADR tests, with the results displayed in the following graph. The curves, which are strictly valid for the samples of the filtering media used in the tests (cut from purchased filters), describe filter performance under 1 micron, where the lowest efficiency is expected to occur. Although with lower efficiency than the other filters, the Camfil panel complies with specifications for F7 class. 3M filters, however, perform much better than expected for its MERV13 rating.

As explained in the report on CADR tests, measured flow rates through the filters are converted to CADR by applying a suitable global efficiency, designated as FERA (Filtration Efficiency for Respiratory Aerosols). The following FERA values are applied for these filters:

- Camfil and Aerostar: FERA=75%, the value suggested for MERV13/F7
- 3M 1900 and 2200: FERA=85%. Although these filters are classified as MERV13, their measured efficiencies significantly exceed specifications.

As noted in Section 5 of this report, these factors were proposed as a conservative representation of the actual performance for the whole size distribution of respiratory aerosols.

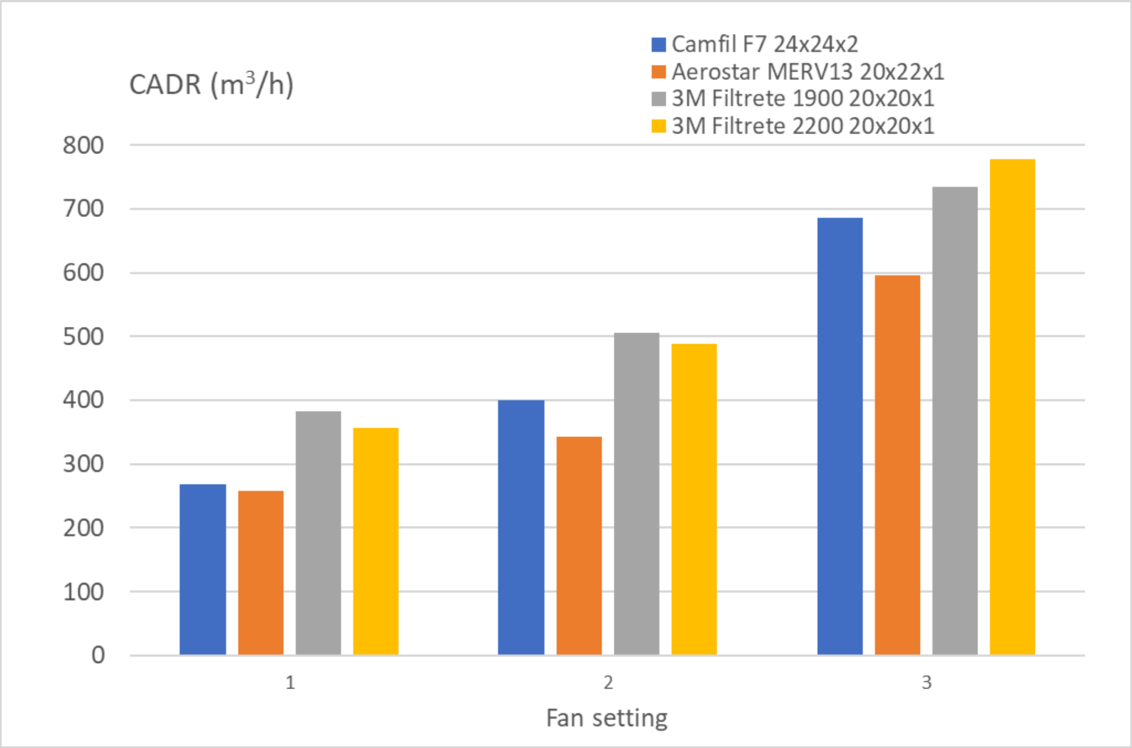


The results for flow rate, CADR, power and noise are given in the table. The graph compares CADR values for the different filters and fan settings.

The highest CADR are obtained with the two 3M filters, with minor differences between them, despite their significantly smaller size (both side dimensions and thickness) with respect to Camfil. In any case, CADR values are notably high for these single panel configurations (for a total cost in the range 55-70€, making it a cost-effective solution with very low €/CADR ratio, even at mid or min speed).

Noise at max speed will limit use in some applications. In those cases, operation at mid or even min speed would be more suitable (always with the option of switching to max for an extra cleaning boost or in periods when noise is not a problem). There are significant (and somewhat surprising) differences among the various filters. 3M 1900 is slightly noisier than its 2200 companion. Aerostar is the quietest one, probably due to being less rigid (but more flimsy) than the other panels.

	Setting	Flow rate (m^3/h)	CADR (m^3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
120 W + Camfil F7 24x24x2	1	357	268	107			
	2	534	401	108			
	3	915	686	119			
120 W + Aerostar MERV13 20x22x1	1	343	257		48.8	47.4	47.1
	2	458	344		51.5	52.5	48.5
	3	795	596		64.4	64.8	57.7
120 W + 3M Filtrete 1900 20x20x1	1	450	383	101	52.7	52.2	48
	2	596	506	105	57.6	57.7	53
	3	865	735	121	67.4	67.8	62.8
120 W + 3M Filtrete 2200 20x20x1	1	420	357	101	48.6	49	46.1
	2	574	488	104	54.8	55.1	52.3
	3	915	778	13	67.1	66.8	63.2

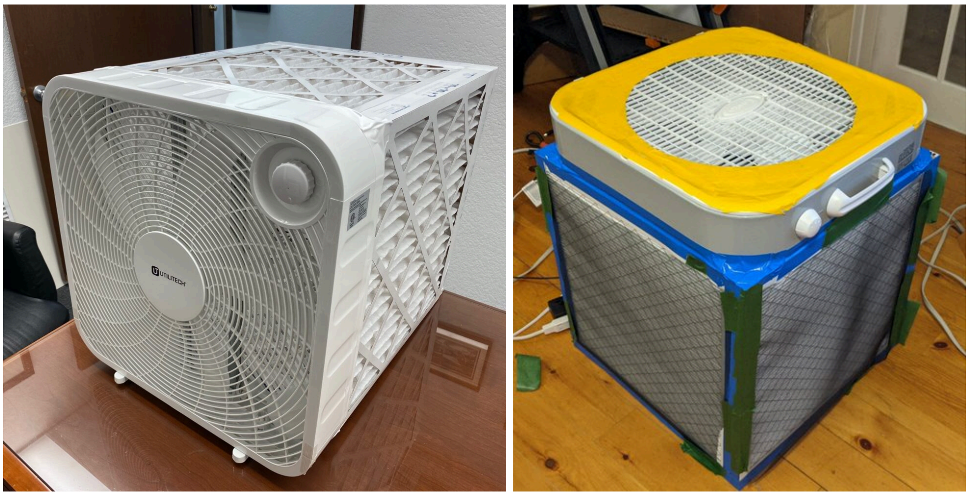


9. Cage fan (120 W) + 4-filter boxes

Air flow rate through the filters (and CADR) are limited by the rather low pressure drop provided by comfort fans (like gym fans or US box fans) used in DIY devices. Increasing the total surface area of the filter is an effective means to reduce flow resistance. Panels with larger thickness or a high number of pleats are some good options in this regard.

The use of multiple filters is also a very effective solution. This is the case of the popular Corsi-Rosenthal box (named after R. Corsi and J. Rosenthal), with 4 filters forming a box, so that the total surface area of filtration media is multiplied by 4. This greatly reduces pressure drop for a given flow rate or, conversely, the total flow rate significantly increases for a given pressure (a few tens of Pascal for comfort fans). An additional benefit is a longer duration of the filters before they need to be replaced.

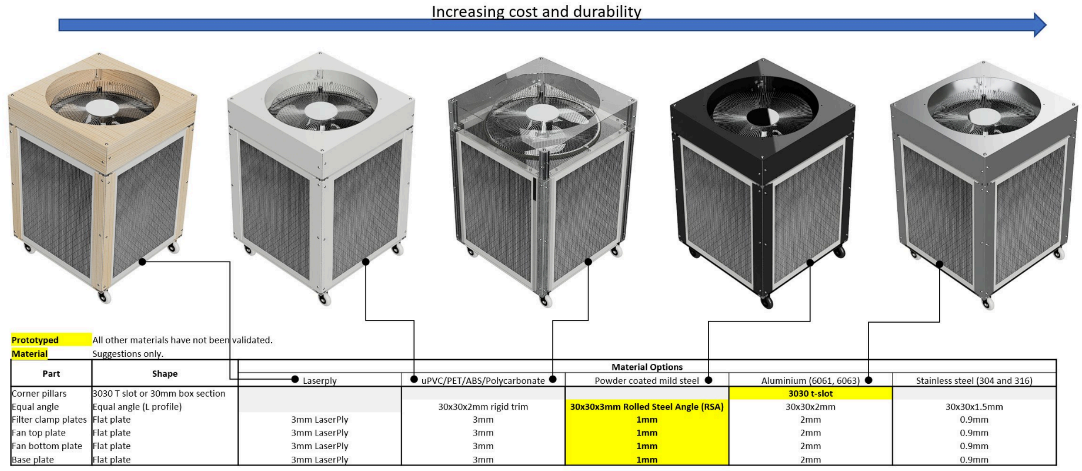
These are examples of a typical Corsi-Rosenthal box (also named Comparetto cube). The one on the right features the shroud proposed by Jim Rosenthal and David Elfstrom to increase flow rate. Thanks to the great and selfless work of these people and others, these designs have been very successful in the US and are already protecting many homes, schools, etc. Info on CR boxes can be found in twitter (in particular, from Jim and David) and many other sources, like the thorough compilation in CleanAirCrew.org.



Square box fans are very cheap in the US and very convenient for this design, as they perfectly fit as a side of the box. However, this model cannot be found in Europe (and other parts of the world), so new designs have been required to adapt the fans available.

Due to its good performance and relatively low cost, cage fans appear as a good option also for filter boxes. Among his many contributions to create new, viable solutions with components available in the EU and UK, Stefan Stojanovic has developed a number of designs to assemble cage fans with the filter box in a notably easy, aesthetic and robust way. This is an example of the info that can be found in this link:

Material specifications



Prototyped All other materials have not been validated.
Material Suggestions only.

Part	Shape	Material Options				
		Laserply	uPVC/PET/ABS/Polycarbonate	Powder coated mild steel	Aluminium (6061, 6063)	Stainless steel (304 and 316)
Corner pillars	3030 T slot or 30mm box section				**3030 t-slot**	
Equal angle	Equal angle (L profile)		30x30x2mm rigid trim	**30x30x3mm Rolled Steel Angle (RSA)**	30x30x2mm	30x30x1.5mm
Filter clamp plates	Flat plate	3mm LaserPly	3mm	**1mm**	2mm	0.9mm
Fan top plate	Flat plate	3mm LaserPly	3mm	**1mm**	2mm	0.9mm
Fan bottom plate	Flat plate	3mm LaserPly	3mm	**1mm**	2mm	0.9mm
Base plate	Flat plate	3mm LaserPly	3mm	**1mm**	2mm	0.9mm

We have not measured actual flow rate for the cage fan with 4-filter boxes[2], but it can be estimated from the fan and filter characteristics. The calculations were done under the assumption that the flow resistance is inversely proportional to the total surface area of the filters. The flow rates estimated in this way were compared with actual measurements for a few cases with simple construction (fan directly assembled on the box, using cardboard and tape to adapt and seal it), always yielding deviations within 10%. It cannot be discarded, however, that discrepancies could be somewhat larger for other box configurations.

All the results are for the 120 W cage fan already described in previous sections. Three filters have been considered: Camfil F7, 3M 1900 and 3M 2200. Their filtration efficiencies are given in the previous section, along with CADR for single-filter configurations. The calculations have been performed for two different panel sizes: 20x20 and 24x24, so as to compare the filters on a common basis. Other typical sizes like 20x25 would yield intermediate values. Thickness, however, is different: 2" for Camfil (which seems the optimal one for this model) and 1" for the two 3M models.

As in the previous section, and taking into account the different filtration efficiencies of Camfil and 3M, the filtration efficiency for respiratory aerosols applied to convert air flow rate into CADR is FERA=75% and 85% for Camfil and 3M, respectively.

The following tables and figures show the values obtained for the different combinations of the same fan (120 W cage fan) with 4-filter boxes. A few comments on these results:

- The larger panels (24x24) yield flow rates that are between 8 and 20% (average 13%) higher than with the smaller ones (20x20).
- The results for the two 3M panels are similar, and between 8 and 26% (average 14%) higher than for Camfil.

---

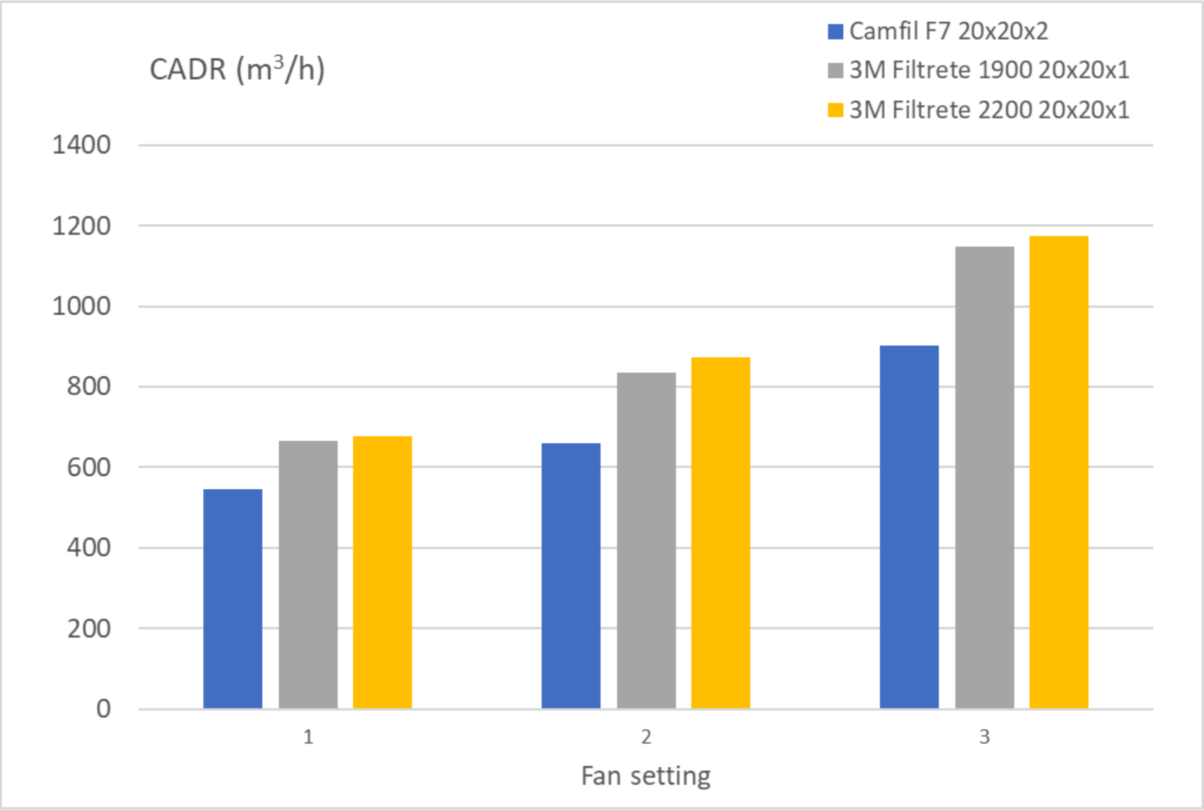
[2] Actually, we did for a specific filter model, but this turned out to have a filtration efficiency much lower than expected and so it is not a recommended option. In any case, these results were very useful to validate the estimates reported in this section.

- Estimated CADR with 4-filter boxes is between 1.5 and 2.2 times (average 1.75) the one measured with single-panel versions. (Note: the difference between single and 4-panel varies with the particular fan-filter combination. We have measured larger differences -of the order of 2.5 times- in other cases. Some data in that regard will be added to this document in the near future).
- Noise was not measured for these combinations. If the differences found between single-panel and box for Honeywell Turbo (see previous sections) also hold for these cases, expected noise for the gym fan + CR box would be expected to be between 2 and 6 dBA lower with respect to the value listed in the previous section for the same cage fan.

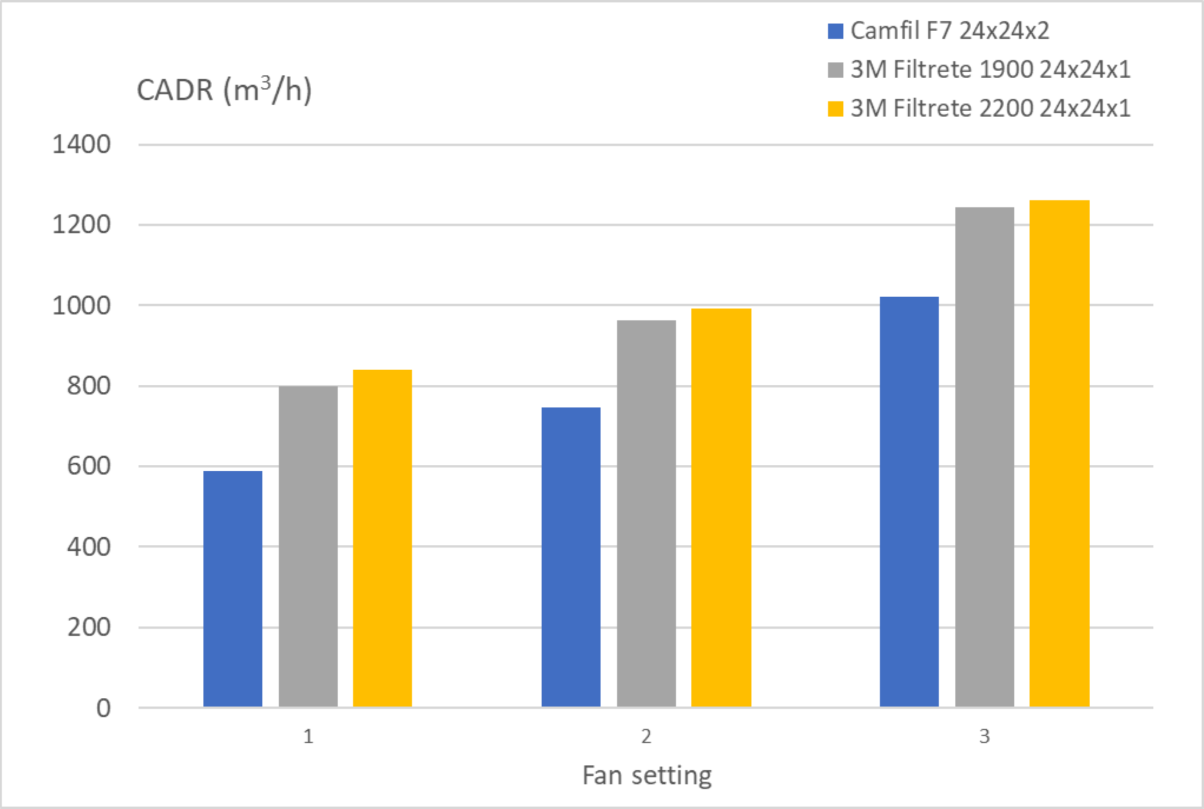
As it has been already noted, construction details can result in some differences with respect to these estimates. Some interesting results in this regard can be found in:

https://twitter.com/PlasticFull/status/1469788287103606796

	Setting	Flow rate (m^3/h)	CADR (m^3/h)
120 W + Camfil F7 20x20x2	1	726	545
	2	878	659
	3	1202	902
120 W + 3M Filtrete 1900 20x20x1	1	783	666
	2	984	836
	3	1352	1149
120 W + 3M Filtrete 2200 20x20x1	1	796	677
	2	1026	872
	3	1380	1173



	Setting	Flow rate (m^3/h)	CADR (m^3/h)
120 W + Camfil F7 24x24x2	1	786	590
	2	995	746
	3	1360	1020
120 W + 3M Filtrete 1900 24x24x1	1	941	800
	2	1134	964
	3	1462	1243
120 W + 3M Filtrete 2200 24x24x1	1	989	841
	2	1166	991
	3	1484	1261



10. Sichler Box Fan + MERV13/F7 panels

Box fans like those used for Corsi-Rosenthal boxes in the US are hard to find in Europe. The only one we have identified (thanks to Markus Leutwyler) can be purchased at:

https://www.pearl.de/a-NX6414-3033.shtml?vid=953&curr=DEM

Current price: 79.9 € + shipping costs (in Sept/2021, we paid 56.9 € + shipping costs).

With 60 W and 48 cm in diameter, this is how it looks:

The appearance is very similar to 60 W box fans commonly found in the US (although at a cost 3-4 times higher), but it is not certain that performance is the same. Max pressure difference, measured in the test bench with closed valve (flow rate=0) was 14 Pa (further details available, for anyone interested).

This section reports different sets of data obtained with this fan and several MERV13 / F7 panels:

- Camfil Ecopleat F7 (ePM1 55%), Size 24x24x2.
- Aerostar MERV13, Size 20x22x1.
- 3M Filtrete 1900, MERV13, Size 20x20x1.
- 3M Filtrete 2200, MERV13, Size 20x20x1.

As in previous sections, the filtration efficiency for respiratory aerosols (FERA) applied to convert air flow rate into CADR is 75% for Camfil and Aerostar, and 85% for 3M Filtrete 1900 and 2200.

10.1 Single panel, no shroud

The basic construction consisted in mounting the filter at the back of the fan and sealing them with duct tape[3]. The tests were conducted at mid and max speeds (settings 2 and 3), but not at min. The following table and graphs display the results obtained for the different combinations, in terms of flow rate, CADR and noise (only for the two Filtrete).

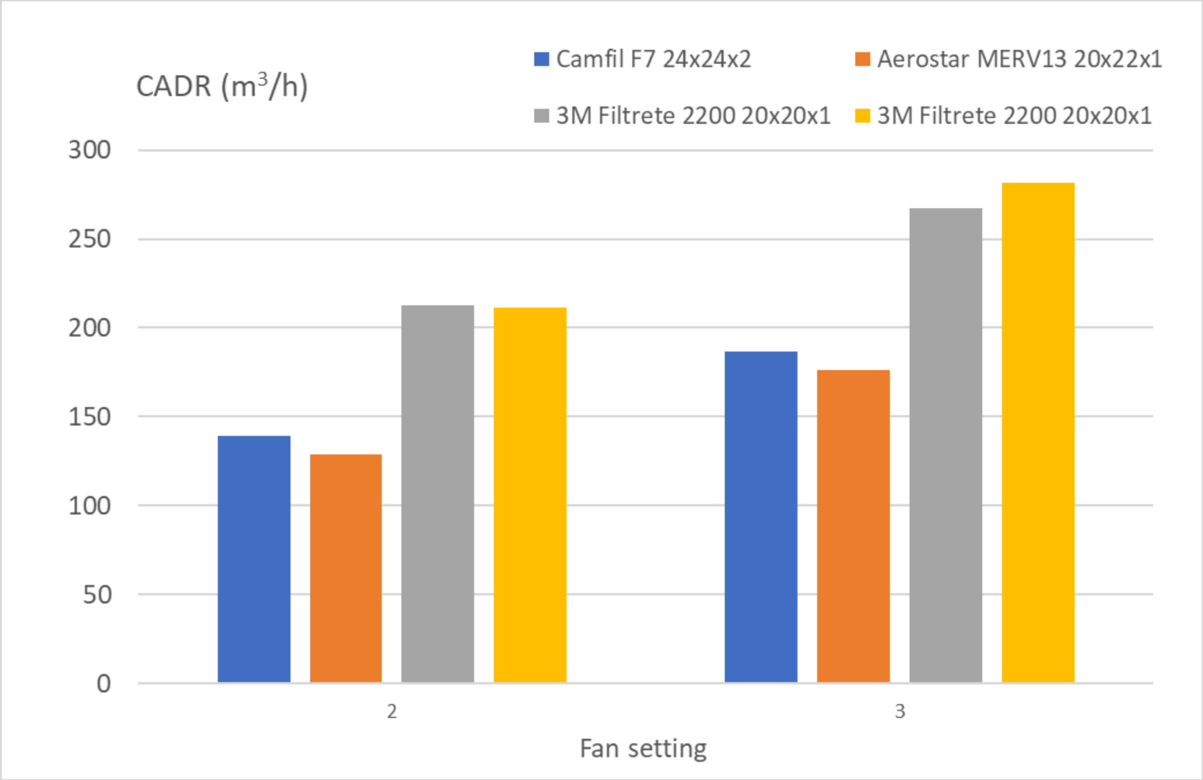
---

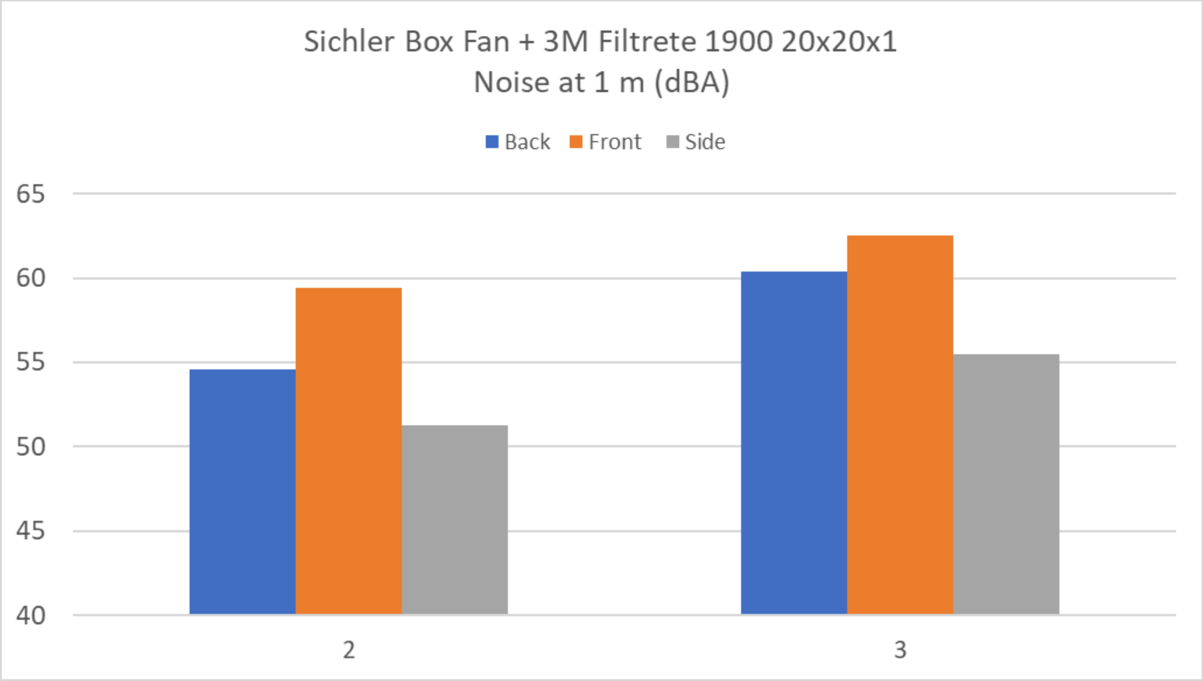
[3] Same tests with the filter mounted on the front of the fan yielded the same flow rate.

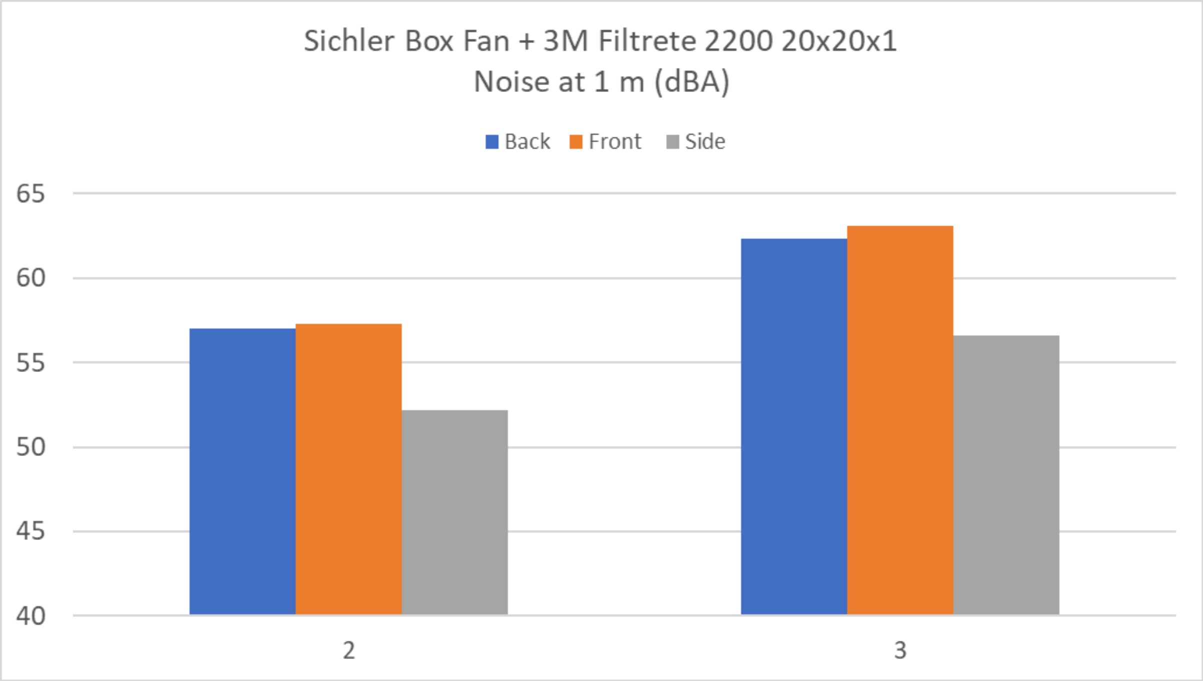
These results can be compared with those obtained with the Duronic (Section 5), for the same power (60 W). In general, lower CADR and louder noise for this box fan.

Although the fan power is different, the comparison of this box fan with the measurements for the 120 W cage fan at settings 1 and 2 (Section 8) is also relevant, both in terms of noise and CADR (higher CADR for 120 W fan, for the same or even lower noise).

Sichler Box Fan (60 W) ***No shroud***	Setting	Flow rate (m^3/h)	CADR (m^3/h)	Power (W)	Noise at 1 m (dBA)		
					Back	Front	Side
Camfil F7 24x24x2	2	186	139	52.0			
	3	249	186	57.8			
Aerostar MERV13 20x22x1	2	172	129	51.5			
	3	235	176	57.2			
3M Filtrete 1900 20x20x1	2	250	213	53.0	54.6	59.4	51.3
	3	315	267	58.5	60.4	62.5	55.5
3M Filtrete 2200 20x20x1	2	249	211	52.4	57	57.3	52.2
	3	332	282	58.6	62.3	63.1	56.6

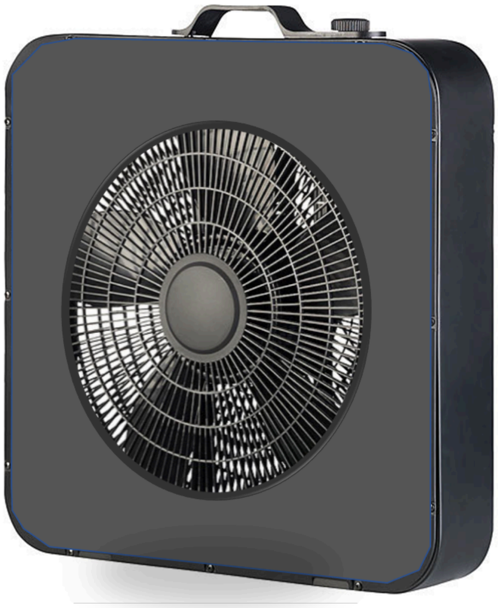



Sichler Box Fan + 3M Filtrete 1900 20x20x1
Noise at 1 m (dBA)
Back
Front
Side
65
60
55
50
45
40
2
3


Sichler Box Fan + 3M Filtrete 2200 20x20x1
Noise at 1 m (dBA)
Back
Front
Side
65
60
55
50
45
40
2
3

10.2 Single panel, shroud of 35 cm

David Elfstrom and Jim Rosenthal have proposed to add a ‘shroud’ so as to restrict the open area at the fan outlet, as illustrated in the following image:



David found that the shroud can yield a significant increase in flow rate. His results, pictures and further info can be found in:

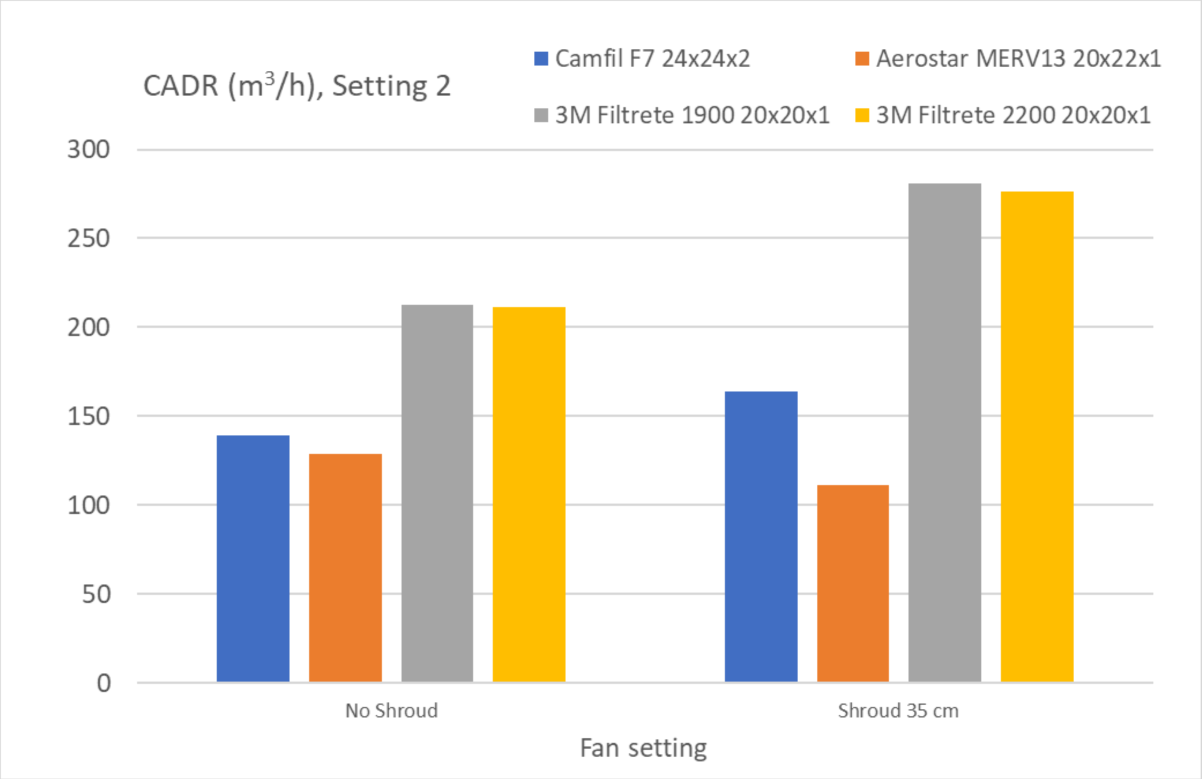
https://twitter.com/DavidElfstrom/status/1429526273009889286

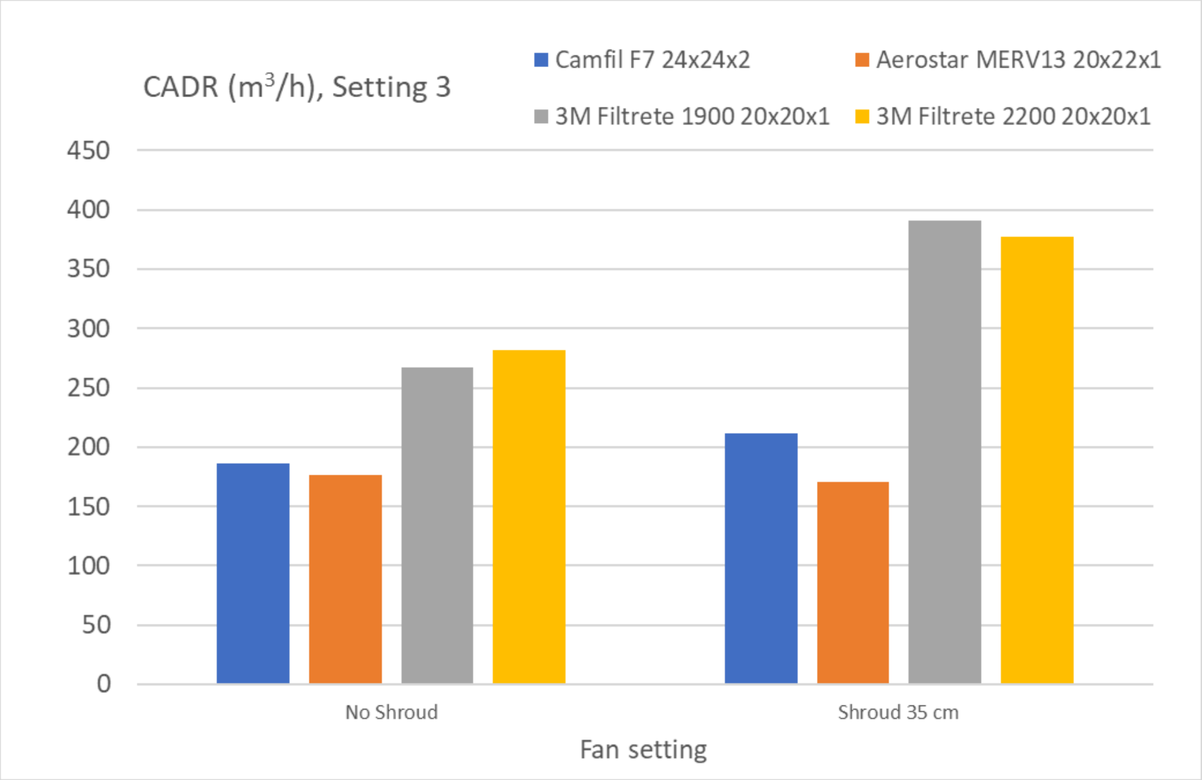
The following table lists the results obtained for the Sichler fan with a shroud of 35 cm in diameter. The flow rates measured with this shroud size are compared with the corresponding cases without shroud in the graphs, for fan settings 2 and 3.

For the two 3M Filtrete panels, the addition of the shroud results in a significant increase in CADR: between 31% and 46%. The shroud also has a positive effect with the Camfil panel, although the difference is not so big: 18% and 13% for settings 2 and 3, respectively. Surprisingly, the tests with the Aerostar panel resulted in some reduction at mid speed and had practically no effect at setting 3 (this seems a rather surprising result that would require further verification and analysis).

In summary, it can be concluded that, as proposed and verified by D. Elfstrom and J. Rosenthal, the shroud has quite positive effects on flow rate/CADR in most cases. The magnitude of the difference depends on the particular fan/filter combination.

Sichler Box Fan (60 W) ***Shroud 35 cm***	Setting	Flow rate (m^3/h)	CADR (m^3/h)	Power (W)
Camfil F7 24x24x2	2	219	164	52.1
	3	282	211	57.2
Aerostar MERV13 20x22x1	2	148	111	51.5
	3	227	170	57.0
3M Filtrete 1900 20x20x1	2	330	281	51.3
	3	460	391	57.3
3M Filtrete 2200 20x20x1	2	325	276	51.3
	3	444	377	57.2




CADR (m³/h), Setting 3
Camfil F7 24x24x2
Aerostar MERV13 20x22x1
3M Filtrete 1900 20x20x1
3M Filtrete 2200 20x20x1
450
400
350
300
250
200
150
100
50
0
No Shroud
Shroud 35 cm
Fan setting

11. Arctic P12 + Filter IKEA Starkvind

Results from tests of a DIY box with Arctic P12 + IKEA Starkvind, built by @SergioCoscolin, with a configuration similar to that proposed by @robwiss (see https://twitter.com/robwiss/status/1584723252340891648). Sergio also kindly provided all the photos and links included in this section.

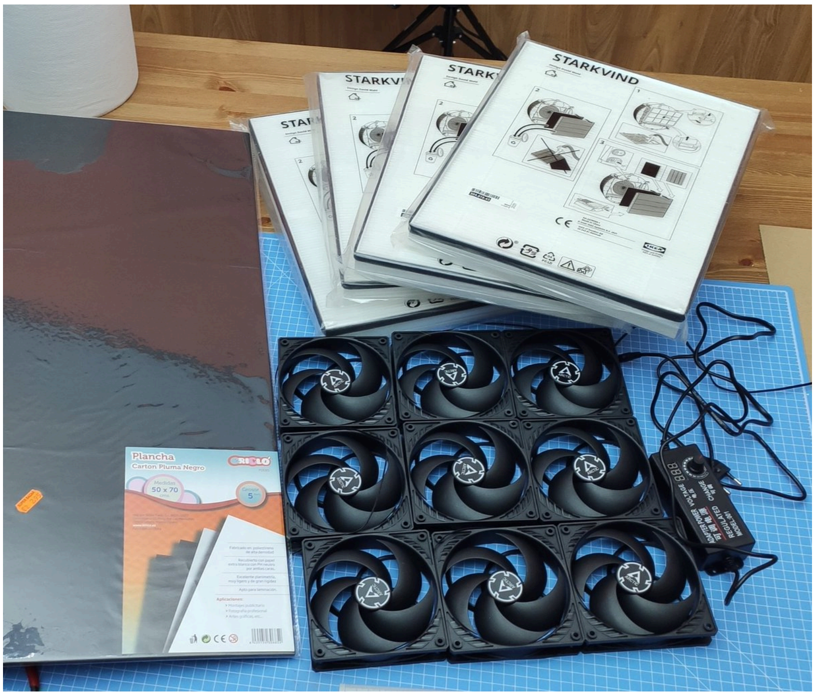
The box consisted of 2 IKEA Starkvind filters + 5 Arctic P12 fans (120 mm):

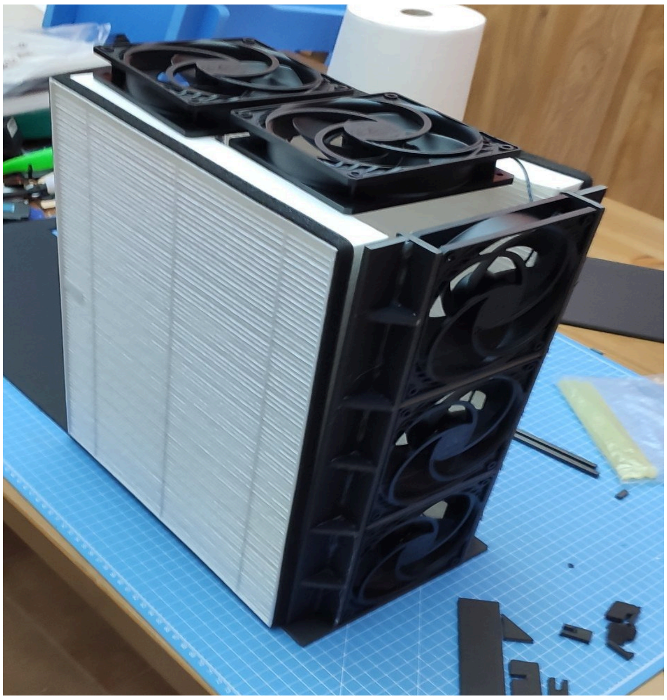
https://www.ikea.com/es/es/p/starkvind-filtro-extraccion-particulas-30461943/

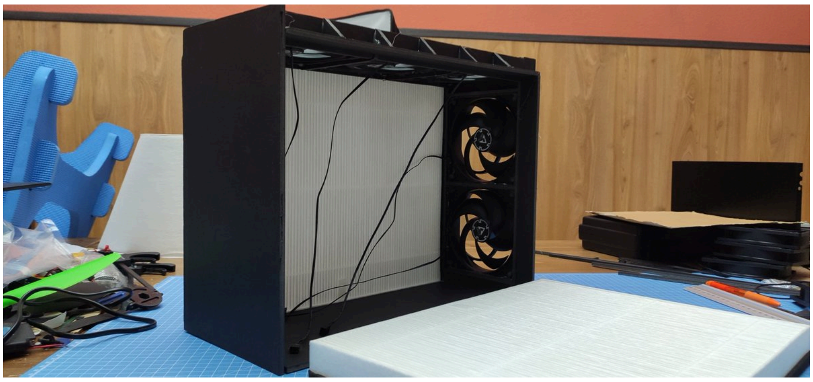
https://www.amazon.es/dp/B07HC7P3HJ?ref_=cm_sw_r_apan_dp_T5CNY04NSBNYX3D15ETB&th=1

ADAPTER POWER
VOLTAGE
REGULATED
MODEL:DMD-034
CHANGE

https://www.amazon.es/dp/B09K7QSVTK?ref_=cm_sw_r_apan_dp_8694S2ECCB9624GXFF0F


STARKVIND
Plancha
Cartón Pluma Negro
50 x 70





We measured air flow rate for different combinations of filters and fans. CADR can be calculated by multiplying air flow rate by an estimated filtration efficiency of 95% (FERA, obtained from the filtration curve reported in Section 6 above and the assumed distribution for respiratory aerosols, as discussed in the report on CADR tests).

	Flow rate (m^3/h)	CADR (m^3/h)
5 Arctic P12 + 2 Starkvind	182	173
3 Arctic P12 + 2 Starkvind	151	143
5 Arctic P12 + 1 Starkvind	109	104
3 Arctic P12 + 1 Starkvind	95	90

Other data:

- Power consumption: 10 W for 5 fans.
- Noise: not measured, but remarkably low noise, both with 3 and 5 fans. Indeed, much quieter than any of the commercial units we have tested (at full speed, as they should be used to obtain the nominal CADR).
- Cost: The following table displays cost data for different combinations of fans and filters.

	CADR (m^3/h)	Cost (€)	€ / CADR
5 Arctic P12 + 2 Starkvind	173	66	0.38
3 Arctic P12 + 2 Starkvind	143	56	0.39
5 Arctic P12 + 1 Starkvind	104	53	0.51
3 Arctic P12 + 1 Starkvind	90	43	0.48

In summary, a very good option for DIY air cleaners: compact design, low power consumption, low €/CADR and very low noise. CADR is not very high, but can be easily solved by building bigger boxes with more filters and/or fans or installing several units (with the additional advantage of a more distributed supply of clean air in large rooms).

Thanks to @SergioCoscolin for providing the prototype for the tests as well as the photos and technical info.

12. Filter at back *vs.* front

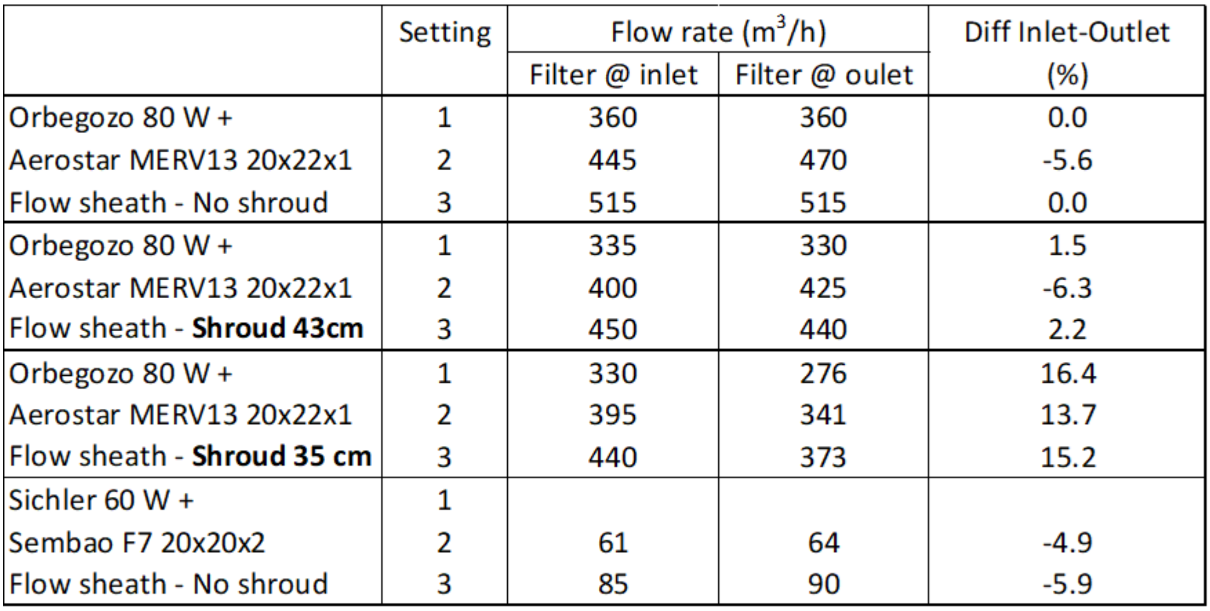
Better to mount the filter at the fan inlet (back) or outlet (front)? We did a few tests to provide some data that could help to answer this frequently asked question.

The following table displays the results for different fans and filters:

- Orbegozo 80 W is a 50 cm round fan (see Part 1):

BF2

- Sichler 60 W is a square fan: see Section 10 of this report.



	Setting	Flow rate (m^3/h)		Diff Inlet-Outlet (%)
		Filter @ inlet	Filter @ oulet	
Orbegozo 80 W + Aerostar MERV13 20x22x1 Flow sheath - No shroud	1 2 3	360 445 515	360 470 515	0.0 -5.6 0.0
Orbegozo 80 W + Aerostar MERV13 20x22x1 Flow sheath - **Shroud 43cm**	1 2 3	335 400 450	330 425 440	1.5 -6.3 2.2
Orbegozo 80 W + Aerostar MERV13 20x22x1 Flow sheath - **Shroud 35 cm**	1 2 3	330 395 440	276 341 373	16.4 13.7 15.2
Sichler 60 W + Sembao F7 20x20x2 Flow sheath - No shroud	1 2 3	 61 85	 64 90	 -4.9 -5.9

- Negligible differences in the cases without a shroud (1st and 4th rows).

  In all cases we used a ‘flow sheath’, so that there is no leak between fan and filter. This was demonstrated to significantly increase CADR due to an effective use of the full filter area (see Sections 1 and 2). The results, with regard to inlet vs. outlet, could be different if the filter is just strapped on the fan (as shown in Section 1).

- There is a difference when a shroud is mounted on the front of the fan to close a part of the outlet: for the 35 shroud, the flow rate is about 15% higher with the filter installed at the back.

Note: the shroud was found to have a negative effect for this particular fan (and, probably, for circular fans in general?). The shroud in this case is thought to cause some flow blockage, without any benefit due to avoiding reverse flow through the corners, as demonstrated for square fans commonly used in the US (see results from @JimRosenthal4 or @DavidElfstrom) or for the Sichler model (Section 10 above).